Risk Management Strategies for Developing Complex Space Systems

by

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Abstract

Risk management strategies have become a recent important research topic to many organizations as they prepare to develop the revolutionary complex systems of the future. Future multi-disciplinary complex space systems will make it absolutely essential for organizations to practice a rigorous, comprehensive risk management process, emphasizing thorough systems engineering principles to succeed. Proactive efforts to reduce or eliminate risk throughout a project’s lifecycle ideally need to be practiced by everyone involved.

Motivation for this thesis research was driven by the opportunity to support the implementation of the NASA Integrated Action Team (NIAT) Report actions. The research focuses its emphasis on the NIAT theme entitled Understanding and Controlling Risk. Synonymous with the “systems perspective” of the MIT System Design and Management (SDM) program, the research content also contains key findings that are broadly applicable to the remaining NIAT themes, as well as to other complex system development organizations in general. Key factors which affect the outcomes of projects were analyzed in an attempt to help the efforts by NASA to better educate the agency and its partnership organizations on Faster, Better, Cheaper (FBC) project implementation. The National Reconnaissance Office (NRO) Commission Report, the U.S. Air Force Science and Technology Workforce Report, and Defense Advanced Research Projects Agency (DARPA) Reports were studied and used to formulate relevant risk management strategies for organizations today that develop revolutionary complex space systems.

Risk management perspectives of senior managers and project managers from aerospace and aeronautical organizations are collected by the use of in-person interviews and electronic surveys. Some of the programmatic risks which drive the success or failure of projects are revealed. A number of complex system projects with revolutionary technologies are also evaluated to determine project manager approaches to the management of programmatic risks. Any interesting differences between the perspectives of senior managers and project managers are discussed. Key findings lead to a number of recommendations for organizations to consider for proactively approaching the programmatic risks which face a complex space systems project early in its lifecycle.

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# Table of Contents

I. Chapter 1: Introduction................................................................. 8  
   a. Background ........................................................................ 8 
   b. Thesis Connection to the NIAT Report ................................. 10 
   c. Relevant Experiences in Other Federal Agencies .................... 12 
   d. Thesis Objectives ................................................................ 15 
   e. Thesis Hypotheses ............................................................... 16 

II. Chapter 2: Research Methodology ............................................ 18  
    a. Data Collection by In-person Interviews ............................... 18 
    b. Data Collection by Senior Manager Electronic Surveys .......... 18 
    c. Data Collection by Project Manager Electronic Surveys ........ 18 
    d. Why Two Different Electronic Surveys? ............................... 19 
    e. Software Technology Used for Developing Electronic Surveys . 19 
    f. Language Processing Method for Organizing Main Themes ...... 20 
    g. Senior Manager Risk Driver Survey Description .................. 20 
    h. Project Manager Risk Driver Survey Description .................. 20 
    i. Common Questions on Both Surveys .................................... 22 
    j. Data Analysis Techniques .................................................. 22 
    k. Potential Sources of Error .................................................. 23 
    l. Literature Sources ............................................................. 23 

III. Chapter 3: Risk and its Management ........................................ 25  
    a. What is Risk? ..................................................................... 25 
    b. What is “Acceptable” Risk? ............................................... 26 
    c. Types of Risk ..................................................................... 26 
    d. What is Risk Management? ................................................. 27 
    e. Some Concepts for Effective Risk Management ..................... 28 
    f. NASA Interview Perspectives on What Drives Risk ................ 31 
    g. Public Perception of Failure ............................................... 34 
    h. Summary of Key Findings .................................................. 35
# Table of Contents (cont'd)

## IV. Chapter 4: Attitude Toward Risk Management

- a. Responsibility for Risk Management ................................................. 38
- b. Project Phases to Emphasize Risk Management Practices ................. 39
- c. Prioritizing Projects Across Standard Measures ............................ 39
- d. Perspectives on the Faster, Better, Cheaper Paradigm ..................... 40
- e. Product Development Processes ................................................... 42
- f. Product Development Challenges ............................................... 43
- g. Shortening Project Completion Time ............................................. 45
- h. Insufficient Funding Early in a Project Lifecycle ........................... 46
- i. Summary of Key Findings ......................................................... 46

## V. Chapter 5: Project Preparation .................................................. 48

- a. Part I: Initial Resources Allocation ................................................ 48
- i. Percentage of Total Budget Requested ........................................ 48
- ii. Percentage of Personnel Requested ............................................. 49
- iii. Schedule Buffer Allocation ....................................................... 49
- iv. Funding Start for Highest Risk Technologies ............................... 50
- v. Influence of Other Projects on Technology Selection ..................... 51
- b. Part II: Team Knowledge Readiness ............................................. 52
- i. Percentage of Workforce Sufficiently Trained ................................ 52
- ii. Understanding of the Organization's Strategic Plan ....................... 52
- iii. Understanding of Project Objectives .......................................... 52
- iv. Understanding the Technologies Used ....................................... 53
- v. The Use of Prior Projects ......................................................... 54
- vi. The Use of Prior Lessons Learned ............................................. 54
- vii. Level of Team Confidence ...................................................... 55
- c. Summary of Key Findings ......................................................... 57

## VI. Chapter 6: Project Team Structure ........................................... 60

- a. Team Leader Authority ............................................................... 60
- b. Team Member Collocation ......................................................... 60
- c. Number of Other Projects a Team Member Works .......................... 61
- d. Staffing Changes ......................................................................... 62
- e. Team Member Interchangeability ............................................... 63
- f. Summary of Key Findings ......................................................... 64
Table of Contents (cont’d)

VII. Chapter 7: Project Team Interactions ............................................................... 65
   a. Frequency of Team Meetings ................................................................. 65
   b. Visibility of Master Schedule .............................................................. 65
   d. Summary of Key Findings .................................................................... 67

VIII. Chapter 8: Identification and Control of Risk ........................................... 69
   a. Part I: Identifying Risks ......................................................................... 69
      i. Defining “Appropriate” Risk ............................................................ 69
      ii. Who Identifies & Classifies Project Risks ....................................... 70
      iii. Sudden Risk Communication ......................................................... 72
      iv. Risk Identification Methods ............................................................ 73
      v. Top Three Project Concerns of Senior Managers ......................... 73
      vi. The Strongest Positive and Negative Impacts to a Project ............. 74
   b. Part II: Controlling Risks ....................................................................... 76
      i. Types of Acceptable Project Managers ............................................ 76
      ii. Making Technical Tradeoff Decisions ............................................. 77
      iii. Technology Risk Mitigation Strategy .............................................. 78
      iv. Increase of Project Scope ............................................................... 78
      v. Use of System Architecture and New Technology Peer Reviews .... 79
   c. Summary of Key Findings .................................................................... 81

IX. Chapter 9: Project Progress Measurement .................................................. 85
   a. Metrics Used to Measure Project Progress .......................................... 85
   b. Rigor of Addressing Action Items ......................................................... 86
   c. Schedule Pressure ................................................................................ 87
   d. Schedule Slip ....................................................................................... 88
   e. Performance Degradation .................................................................... 89
   f. Percentage of Project Budget Increased ............................................. 91
   g. Impact of Budget Instabilities ............................................................. 91
   h. Summary of Key Findings .................................................................... 92

X. Chapter 10: Conclusions ............................................................................. 94
   a. Thesis Summary .................................................................................. 94
   b. Future Work ....................................................................................... 101

XI. References ................................................................................................. 102

XII. Appendix A: Senior Manager Risk Driver Survey ...................................... 104

XIII. Appendix B: Project Manager Risk Driver Survey .................................... 108
Chapter 1

Introduction

Background

The National Aeronautics and Space Administration (NASA) has the fundamental charter to continuously push the frontiers of space exploration, science discovery, and technology development. As pioneers and innovators of complex space systems to explore the regions of air and space, NASA leads and inspires America to research, develop, and transfer advanced technologies and systems. NASA is also an investment in America’s future through technology and knowledge transfer. The transfer of many NASA technologies to the private sector aids in strengthening the national economy. The sharing of knowledge gained from successful NASA missions enhances the technological literacy of our nation. With such an agenda, considerable risks are inherent in all that the agency embarks upon. These risks arise from attempting what has not been done before, and are a constant concern because they must be successfully managed with available resources. Thus, a tremendous emphasis upon effective risk management strategies is required in order to achieve success.

NASA Administrator Daniel Goldin [9] has expressed the desire for establishing a virtual presence in space. Aerospace systems of the future are expected to integrate the fields of nanotechnology, biotechnology, and information technology to accomplish this goal. Nanotechnology is the creation of useful materials and systems at the nanometer scale. Biotechnology is the application of biological materials, models, and techniques to pioneer new engineering systems. Information technology will be used to generate smart software agents that sense and interpret the relevant environment, and execute autonomous actions. Tremendous networks of intelligent, evolvable, adaptable systems will be assembled to explore the surfaces of celestial bodies or regions of space. The emergence of space system architectures that are autonomous, increase in intelligence over time, sense and broadly adapt to their unknown environments, and perform self-diagnosis and repair, are vital for achieving this vision for future space missions. This era will also require agile teams working harmoniously together, while disbursed geographically around the world. The merging of the biology and molecular science disciplines with traditional forms of engineering present many unknown risks. Effective risk management processes become a major part of developing these new architectures and operating under these new paradigms.

Part of the research was motivated by this vision of future aerospace systems. Senior managers were asked to describe what changes to their present organization were felt necessary to successfully manage the risks for developing such multi-disciplinary complex space systems. The results appear in Table 1.1. The most popular response is to emphasize the return to the rigorous fundamentals of risk management early in a project lifecycle. Cross-disciplinary training is deemed a critical support mechanism to marry the fields of biology and molecular science with engineering. The increased use of automated tools was also identified. The expectations are to use computer simulation and modeling capabilities, and computer-based risk assessment tools, to the fullest extent possible. This approach would aid in system design as well as for the selection of concepts which hold acceptable levels of uncertainty. Future advances in technology are anticipated to enable opportunities in risk assessment that was
previously unavailable. More systems engineering involvement than traditional systems developments is also expected. The emphasis of pure systems engineering approaches plus the increased number of qualified systems engineers working on the project was cited.

<table>
<thead>
<tr>
<th>Type of Organizational Change</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>More Rigorous Risk Management Practices Early in the Project Lifecycle</td>
<td>27.2</td>
</tr>
<tr>
<td>Cross-Disciplinary Training</td>
<td>22.7</td>
</tr>
<tr>
<td>Greater Use of Automated Tools</td>
<td>18.2</td>
</tr>
<tr>
<td>More Systems Engineering Involvement</td>
<td>13.6</td>
</tr>
</tbody>
</table>

Table 1.1 Changes Needed for Developing Bio/IT/Physical Complex Systems

The development of space exploration vehicles and systems is a complex and challenging endeavor, as observed by such prior accomplishments as the Space Shuttle, the International Space Station, the Hubble Space Telescope, and a variety of robotic spacecraft (e.g. orbiters, landers, and rovers) to explore Mars and the other planets of our solar system. To obtain the necessary skills and keep within the budgets of these considerable undertakings, NASA plans and coordinates technological research and development both in-house and with external partners. The agency serves as a catalyst for forming teams among academic, government, and commercial institutions to draw upon the best capabilities of each for developing new technologies and managing space missions. The best technology development practices and business processes are required such that an acceptable level of risk is maintained while achieving optimal performance, yet minimizing costs and schedule. Under NASA’s “Faster, Better, Cheaper” philosophy, shorter mission lifecycles and increased frequency of missions have tested the agency’s resilience to failure in recent years. Essential to meeting the needs of these complex space systems developments is the teamwork that occurs across many organizational boundaries. Looking at a popular example, Figure 1 illustrates the geographically distributed organizations that collectively support Space Shuttle systems development, testing, launch activities, mission operations, and refurbishment [24]. The Space Shuttle is a highly successful example of the development and operation of an incredibly complex space system, thanks to the comprehensive processes by which risks are scrutinized and mitigated. As one interview respondent described, “For human space flight, failure is not an option.” Nonetheless, NASA has unfortunately experienced several significant mission failures in recent years due to the present day challenges it has faced. Failure examples include the Mars Climate Orbiter, Mars Polar Lander, and Space Shuttle fuel leaks and wiring harness problems. Important risk management lessons learned have emanated from the reports released by the failure review boards for these missions.

One major recent challenge has been the downsizing of federal agencies, as well as some aerospace contractor firms, causing the experience base of the aerospace community to substantially decline during a time period of increased number and complexity of aerospace initiatives. This has led to a loss in both corporate knowledge and essential skills, increasing space mission risk. This is further exacerbated by the aging population a government agency such as NASA is presently comprised of, meaning that the most experienced personnel are soon coming up for retirement. As of the end of year 2000, the demographics of NASA consisted of
three times more employees over the age of 60 than under age 30. Capturing the wealth of experience from the minds of the veteran project managers and technical specialists before they depart the agency, is a challenge that may pose more difficult than any of the actual space endeavors. Also, with reduced workforce levels, the time-sharing of engineers across multiple projects has been a common approach to meet the needs of the many projects ongoing simultaneously. The approach for meeting the workforce needs of the many missions ongoing simultaneously become a factor affecting the outcomes of the programs pursued.

Figure 1. US Sites Supporting the Space Shuttle Program

Another major challenge for NASA is that as a federal agency, it is accountable to many stakeholders. Technical decision-making sometimes occurs in an environment of political policies and influences. Since these types of influences are a certainty with respect to the federal process, a project manager often faces these influences that are out of his/her personal control. A risk management plan that includes mitigation strategies for absorbing politically driven changes is crucial for limiting the potential probability negative impacts to projects. In addition to NASA, organizations including the United States Air Force (USAF) and the National Reconnaissance Office (NRO) have recently evaluated such influences on their program and project activities. Some of their relevant findings are discussed in several areas of this document.

Thesis Connection to the NASA Integrated Action Team (NIAT) Report

The NASA Integrated Action Team Report [13] was released in December 2000 to provide a integrated framework for addressing the recommendations that emanated from several recent failure review board reports, and to formulate proactive steps for Agency improvement. The results of the Mars Climate Orbiter (MCO) Mishap Investigation, the Mars Independent Assessment (MPIA), the Faster, Better, Cheaper (FBC) Task, and the Space Shuttle Independent Assessment (SIA) were gathered as inputs to the NIAT report. The NIAT report developed 17 high-level actions for the long-term improvement of the planning and execution of NASA
programs and projects. These actions are sorted into 5 key implementation themes, which are now described.

1. Developing & Supporting Exceptional People and Teams

NASA has set a long-term goal of being a continuous learning organization to sufficiently support its individuals and project teams. Both formal training and work experience are essential to proactively sustaining the required capabilities of the workforce. The ultimate success of NASA is dependent upon a knowledgeable and skilled workforce, who possess the ability to apply the necessary engineering techniques, processes, and methods, with the right tools to simplify and improve the robustness of designs. This theme also focuses on approaches for effectively balancing the workload of individuals.

2. Delivering Advanced Technology

To meet NASA's ambitious strategic plan, new technologies must be successfully developed for both current and future space missions. A three-pronged approach to technology development is envisioned. The first element is a balanced technology investment strategy to maintain a portfolio of mature, demonstrated technologies for supporting the needs of near-term and mid-term space missions. Part of this portfolio is to include revolutionary technology developments that will enable new missions in the 21st century. The second element is a well-defined planning process. This process must identify new technologies to develop and implement, identify emerging technological paradigms, define new opportunities, and ensure the successful insertion of these technologies into space missions. The third element focuses on the technology lifecycle. From basic research through application, technology development must be accomplished in a sensible, yet thorough manner to assure that performance requirements are met and projects prosper from these technologies. Due to shorter mission lifecycles, NASA needs to find ways to accelerate the introduction of new technologies into missions.

3. Understanding and Controlling Risk

By the unique nature of NASA undertakings, every mission is unique and carries with it inherent risks. Consistent with pushing the envelope of science and technology discovery, missions must not be risk-averse. Not only is risk management a key factor of project management, the right risks must be identified, assessed, tracked, and continuously managed by the project team, and accepted by management, customers, and stakeholders. Mission success criteria must be made clear to all levels of management, including ascertaining a coherent definition of the acceptable risks for the project. Team members must fully understand their role in the identification and control of risks. A proper balance between the project scope and available resources must be attained. Primary responsibility for effective risk management rests solely with the project manager.

4. Ensuring Formulation Rigor and Implementation Discipline

New policies, practices, and processes must be fully understood by all levels of the organization. Application of these policies, practices, and processes must occur with discipline throughout the entire project lifecycle. To assist the project team in this regard, comprehensive reviews, a risk-based supplier surveillance strategy, and a comprehensive verification and validation program are essential. More direct engagement of the skills and experience of institutional managers and independent experts are required. A new cultural environment must
be created that allows creativity and innovation to thrive in order to cultivate the proactive management of NASA missions.

5. **Improving Communication**

The recent NASA mission failure reports repeatedly cited the need for improving communication at all levels of the organization. Critical information must be made readily available. Supportive tools must be used to boost communication. Open and candid communications must be fostered as the norm, with rewarding successful communication practices. The barriers to effective communication must be identified and eliminated.

Motivation for this thesis research was due in part to the release of this report at a time which coincided with the initiation of thesis development. The opportunity to provide support to the beginning stages of NIAT implementation strategies was compelling. A research effort becomes much more stimulating if its results can be of practical use to a cutting-edge problem faced by an organization. The research focuses its emphasis on theme 3, Understanding and Controlling Risk. However, synonymous with the “systems perspective” of the MIT System Design and Management (SDM) program, the research content contains findings broadly applicable to the remaining 4 NIAT themes. This stems from the fact that risk does factor into the many aspects of project planning, development, and execution. In fact, there are interrelationships between all of the NIAT themes from a programmatic risk standpoint.

The paradigm of “Faster, Better, Cheaper” (FBC) has become well-known in product development organizations outside of the aerospace community as well as within. FBC promoted the acceptance of risk by pushing the limits on the technical and programmatic aspects of a project. Experience to date has shown that there has been some difficulty in implementing FBC by NASA Centers and contractor support organizations. Part of the difficulty stems from the paradigm meaning different things to different individuals. Part of the difficulty is also attributed to a three-fold increase in the number and complexity of NASA programs and projects during a time that NASA’s civil service workforce was reduced by 24%. With both an insufficient and inconsistent understanding of FBC principles, the agency still managed to post a mission success rate of 67%. The NIAT report concluded that the proper application of FBC is valid and has applicability to all that NASA does. Therefore, the agency’s goal is to improve FBC knowledge across its workforce in a manner which promotes its application properly and consistently across a variety of future missions. As a result, this research attempts to contribute some useful project risk management findings that can help NASA in its efforts to improve the implementation of FBC.

**Relevant Experiences in Other Federal Agencies**

**National Reconnaissance Office (NRO)**

The NRO released a Commission Report in Fall 2000, which cited a number of recommendations to recent challenges the organization was facing [21]. These recommendations have relevance to NASA. Both NASA and the NRO are large federal agencies which develop space systems to meet their primary goals. In recent years, the NRO has struggled to meet the needs of a changing customer base. Their gradual shift over time from a revolutionary technology focus to an operations focus has caused them to reassess their strategic direction by
assembling a task force to make recommendations for the future. Some aspects of these recommendations are intertwined into discussions which follow in subsequent chapters.

The NRO provides unique intelligence capabilities for maintaining the security of the United States. They develop, acquire, and operate the most sophisticated satellite reconnaissance systems in the world. These satellites serve as a crucial mechanism for protecting national security, by supporting diplomacy, preventing war, monitoring the development of weapons for mass destruction, aiding the war on drugs, and anti-terrorist activities. Similar to NASA, NRO program budgets have become constrained in recent years. This has taken its toll on modern national reconnaissance capabilities, coming at a time where national threats have become the most complex and unpredictable. The disappearance of a single threat since the end of the Cold War era has created a false sense of security, accompanied by a lack of policy direction during a time of an increase in both the complexity and number of threats.

The number of NRO intelligence users have also expanded dramatically. In the environment of constrained resources, the organization has been stretched too thin in its attempts to satisfy the requirements of all of its customers. Great strain has been placed on NRO senior and project managers as customer demands have exceeded present capabilities. Attempts to meet everyone’s needs has received criticism from its customers and the media. Therefore, a balance of competing needs has been recommended for the organization.

There continues to be substantial pressure to maintain current, aging capabilities as opposed to making the investment in higher risk, more advanced technologies. Despite the NRO having developed the past reputation of being the preeminent research, development, and acquisition intelligence organization, the changes it has experienced in recent years have caused a loss in the ability to develop and apply new technologies rapidly. Similar to NASA, information technology has benefited the organization while also challenging it. Since technology represents the key to future space-based reconnaissance access and capability, efforts are being made to return the agency’s expertise of rapidly developing and inserting change technologies. A focus by the NRO on revolutionary technology development is perceived as critical for the United States to remain at or ahead of the leading edge of the global technology revolution. Performance is now deemed more important than constraining costs in the pursuit of new technologies.

The NRO has had its share of difficulties in recent years cultivating and maintaining a highly talented workforce. Constraints on employee career advancement opportunities has placed limitations on their ability to secure a long-term commitment from its technical members. A return to the freedom of engineering creativity and reward for its occurrence is needed to yield the desired performance levels. The application of an end-to-end systems approach was recommended to facilitate the development of breakthrough systems. A cradle-to-grave lifecycle involvement by engineers was also recommended for enhancing the future technological capabilities. The view is that if engineers operate the satellites they build, they develop important insights for developing future capabilities. Experienced program managers are also seen as a key to future success. Highly qualified managers that require little supervision, and are empowered to make important decisions at their level, are seen to be the necessary ingredient for high risk projects to have positive outcomes.
Defense Advanced Research Projects Agency (DARPA)

DARPA is an example of another federal organization whose charter is to embark upon high risk developments in order to push the envelope on technological progress [5]. The DARPA model is a quite interesting one, and several aspects of it have relevance to technology innovation for NASA. One obvious connection is the shared vision of developing future complex systems by the integration of life science with physical science. The present DARPA expects the next generation of innovations to spark from the intersections of life sciences with materials, chemistry, physics, and engineering. Some discussions in subsequent chapters refer to several aspects of the DARPA model.

DARPA over the years has remained a small, flexible agency with a flat organizational structure. It has maintained substantial autonomy and freedom from bureaucratic impediments. It has been successful at continually defending itself against outside influences that would constrain its freedom and flexibility. Its strategy is to position itself to act quickly and decisively with high quality people to create revolutionary capabilities for our nation’s defense. Making it one of the unique research and development organizations in the world is the ability to quickly adapt to changing environments. DARPA embraces risk and innovation, reaching far across the time horizon. It functions as a bottom-up organization, funding ideas wherever they originate. Substantial resources can be applied to a new idea quickly to get it off the ground and running.

DARPA’s mission is to enable radical technology innovation while focusing on national-level problems. The agency maintains a continuous development and exploitation of high risk core technologies to achieve operational dominance for the warfighter, avoid technological surprise, and protect the nation from biological and informational attacks. As these examples illustrate, the agency targets emerging situations and focuses on making a difference by identifying trends, limits, and opportunities.

Typical projects span 4 years and cost between $10-40 million. A single program manager maintains entire control, and is supported by some onsite contractors. The project goals are achieved by the execution of tasks by 5-10 contractor organizations and a few universities. Their business model emulates that of a venture capitalist firm. Thus, there are no bricks and mortar to protect. DARPA simultaneously seeds a lot of innovations, but with frequent turnover. To stay fresh and on top of technological revolution, twenty percent project turnover is expected each year such that the agency completes a 100% turnover every 5 years.

DARPA depends strongly on creative program managers and their unique abilities. They seek program managers that are technically outstanding and entrepreneurial. The program managers serve 3-5 year rotational assignments to ensure fresh thinking and perspectives are sustained. Projects emphasize small teams of the highest caliber people. The primary role of senior managers in the agency is to enable the program managers. Aside from senior managers ensuring wise investments with funding, there are practically no other rules imposed. The program manager has a complete acceptance of failure if the payoff of success was deemed high enough. Constant program reviews are conducted to mitigate potential risks.
United States Air Force

The U.S. Air Force released a Science & Technology Workforce Report in July 1999, which cited recommendations for assuring the world class nature of its science and technology research laboratories (AFRL) over the long term [11]. These recommendations were designed to increase the value of AFRL to the Air Force. Some of the findings from this study are relevant to NASA. As a consequence, some aspects of these recommendations are discussed in chapters which follow.

In order to move AFRL to a more agile, high impact science and technology enterprise, recommendations were made in the key areas of leadership, culture, and personnel practices. The leadership must transform AFRL into a culture which inspires excellence and eliminates mediocrity. A significant core group of exceptional civil servants are necessary to establish continuity. To create the working environment, this core group is integrated with a team of collaborators who bring agility and fresh ideas. Collaborators include post-doctorates, temporary hires, intergovernmental appointments, military officers, and highly respected individuals from private industry. Stable funding on multi-year time scales is recommended for facilitating the necessary cultural and organizational changes.

The leadership team has to modify the AFRL culture into becoming a critical resource to the Air Force. In the past, AFRL was successful in playing a major role in providing the Air Force with technological capabilities for winning wars, e.g. stealth technology, precision guided munitions, and the Global Positioning System. Future essential technological achievements include several directed energy weapons such as the airborne laser, scramjet technology, and clusters of microsatellites. Dramatic change is expected by developing a culture which is responsive, enabling, intellectually stimulating, focused on excellence, and eager to absorb new ideas.

To meet its strategic goals, AFRL was recommended to adopt a policy of recruiting, retaining, and rewarding the best technical people. Promising students should be identified early and tracked throughout their graduate years for potential hiring. To raise the standards of excellence, 3 year probationary periods were recommended, to weed out poor performers. Hiring was suggested to occur every year, regardless of downsizing periods, to maintain a continuous flow of civil servant employees and retain the links that have been established over the years with universities. Bonuses and awards were cited as mandatory for rewarding individuals and encouraging them to stay.

Thesis Objectives

This thesis research attempts to answer the following question:

Given a technological organization whose role is to take considerable risks, what proactive strategies can be implemented in order to increase the chances of success for developing revolutionary complex space systems?

"Revolutionary" implies technology advancements that are breakthrough in nature, such that their use enables new missions that otherwise would be infeasible. "Complex" systems implies those systems which contain many interrelated, interconnected, or interwoven elements and interfaces. Systems which are complex have reached the level of sophistication such that the
relationships between function and form are unrecognizable [19]. Complex systems require a
great deal of information to specify. Complex systems contain numerous components which are
subsystems. The subsystems are often considered a system in itself, and these subsystems must
function in a coordinated way for the complex system to accomplish its goals [16].

As part of the approach to answering this question, the thesis will examine some of the
programmatic risk drivers to the development of complex space systems that push the
advancement of science and technology. It will investigate the potential barriers to project
success, and reveal some of the competing interests. This is done by first exploring the concept
of risk through literature sources and through the data collected from in-person interviews. The
perspectives of senior managers from aerospace or aeronautical organizations will also be probed
to understand the primary risk drivers to projects. The practices of numerous experienced project
managers from a variety of organizations which develop revolutionary, complex products are
also studied to reveal what activities seem to positively or negatively affect project outcomes.
Any differences between the perspectives of senior managers and project managers will be
revealed, and evaluated to understand whether they pose any programmatic risks. Since a senior
manager’s function is to set policies, guidelines, and provide oversight, while the working
project manager carries the direct responsibility for the success or failure of a project, the
comparison is of interest in order to yield any interesting disconnects. Because the topic of risk
management is colossal in magnitude, the thesis will focus on examining the management
approaches to programmatic risks during the early stages of projects.

The results of this study will help to transform the NIAT report actions into implementation
strategies. Research findings will also complement the report with additional aspects, thus adding
to its fundamental list of actions. In most cases the research will provide a confirmation to
NASA of the importance of following through the actions they have already identified. As part
of this endeavor, this research provides useful data on project performance, cost, and schedule
parameters which can aid in the steps toward improving the understanding and execution of
FBC.

**Thesis Hypotheses**

There are a number of hypotheses this research will attempt to validate in chapters 3 thru 9. The
hypotheses are subsets of the fundamental thesis question stated earlier. By first obtaining
answers to the hypotheses, it is expected that a more comprehensive answer to the fundamental
thesis question can be derived.

- What specific individual(s) are perceived to be the most responsible for the effective risk
  management of a project?
- Are risk management steps emphasized early enough in a project’s lifecycle?
- What will most project managers believe to be the primary risk drivers for a project
  implemented under the Faster, Better, Cheaper paradigm?
- What project preparation and planning issues have an affect upon the performance, cost,
  and schedule goals of a project?
- How does team member knowledge preparation influence the outcome of a project?
- How is team confidence affected by the development conditions which face a project?
How do both senior managers and project managers feel about project staffing issues?
What affect on the probability of project success can external influences make?
What will senior managers and project managers consider to be the strongest positive and strongest negative impacts to a project?
What types of methods are being applied by organizations for identifying project risks?
How do the number of peer reviews conducted affect the probability of project success?
What appropriate, well-constructed progress metrics are being diligently used to measure the progress of a project?
Chapter 2
Research Methodology

Thesis data was collected by the use of three instruments: the in-person interview, a senior manager electronic survey, and a project manager electronic survey. These instruments were utilized to obtain the perspectives of senior executives, senior administrative managers, and experienced project managers for what drives the programmatic risks of projects. The approach was to sample a number of projects instead of doing a case study on only one or a few projects. Sampling a sufficient number of managers and individual complex system projects has surfaced a number of underlying issues, approaches, and concerns.

Data Collection by In-person Interviews
Thesis data was gathered by conducting in-person interviews with a number of NASA senior executives from NASA Headquarters in Washington, DC, and Goddard Space Flight Center in Greenbelt, Maryland. The purpose of the in-person interviews was to get the perspectives of executives on risk in various different parts of the agency. The discussion was held with minimal boundary conditions, to take advantage of recording whatever relevant thoughts came to the interviewee’s mind. Since each interviewee possesses a wealth of prior experience for managing various aspects of NASA missions, tapping into these sources of knowledge was uniquely useful for studying the main drivers of programmatic risks. In several cases the interviewee also completed the senior manager electronic survey in advance of the in-person meeting. In these cases, some of the interview time was devoted to expanding on particular survey responses, in order to solidify the contextual information.

Data Collection by Senior Manager Electronic Surveys
A senior manager electronic survey was developed to capture the thoughts of senior managers on their perceptions of how risk drives the projects of their organization. These perspectives are important because they come from an organizational level which is responsible for setting policies, guidelines, and providing oversight. Responses were received from a variety of aerospace and aeronautical organizations. The survey was primarily used as an alternative to an in-person interview. This alternative proved useful for several reasons. The author had limited availability during the semester to conduct in-person interviews. It served as a great way to obtain the participation of a senior manager that is geographically distant, without having to travel to his/her location. In many of the cases, the schedules of the senior managers made it extremely challenging to secure a mutually feasible appointment. A survey provides the forum for receiving answers from multiple respondents to the same set of questions, for statistical correlation. During in-person or telephone interviews, there is a great tendency to deviate from the particular questions as the conversation proceeds, and can result in an incomplete collection of data. There were a total number of 23 senior manager electronic surveys collected.

Data Collection by Project Manager Electronic Surveys
A project manager electronic survey was developed to capture the thoughts of project managers who are directly responsible for the success of a project. Their perspectives on what drives programmatic risk in their projects come from direct experience in managing the effort. Responses were sought from civilian government, military government, and commercial
enterprises. Each of these respondents managed the development of a complex system which included one or more enabling technologies. Although the majority of respondents were primarily managers of complex systems for aerospace or aeronautical applications, several respondents were managers of complex technological products for commerce. The inclusion of commercial project examples was valuable for capturing a variety of approaches to managing risk effectively. The total number of project manager electronic surveys collected was 63.

Why Two Different Electronic Surveys?

Two different surveys were used to target the senior manager and project manager audiences. Since a senior manager has limited time in his/her schedule to complete a survey, there was a compelling reason to make this survey concise. A shorter survey can be completed more expeditiously than a longer survey, and is less likely to turn the person away from completing it due to its length. Thus, a short survey was designed to increase the expected response rate. The senior manager survey contains more open-ended questions than the project manager survey. This is intentional to capture the qualitative thoughts of the senior manager. In contrast, the project manager survey asks a large number of questions, but the questions are primarily quantitative in nature and can be answered quickly (e.g. multiple choice selection, yes/no, and enter a specific number). The project manager survey was designed to collect data appropriate for statistical analysis, with the goals of identifying specific project management characteristics, project manager preferences for reducing programmatic risks, and any drivers that seem responsible for increasing the probability of project failure. Several questions appear on both surveys, to compare the perspectives of both types of managers. The majority of the questions on the two surveys differ from each other. The questions on each survey are designed to focus on some of the specific concerns of that type of manager. The use of two different surveys also expanded the data collection space, by the generation of data to a larger number of questions.

Software Technology Used for Developing Electronic Surveys

The senior manager and project manager risk driver surveys were developed using the Microsoft Word 2000 software program (MS Word) for the PC. The surveys were distributed by email messages to respondents as file attachments. MS Word was chosen because it is the standard word processing software program for portable and desktop computers. It was fair to expect every respondent to have MS Word installed on their computer system, and proficient enough to work with the survey file. The use of MS Word to create a survey template was extremely quick to learn, as well as free of cost. In the interests of preserving time and effort, it was a better choice than generating a web-based survey.

The survey files are MS Word template (.dot) files, and are easy to use by the recipient. A respondent receives an email message requesting their participation for filling out the survey, with the .dot file attached. When the respondent clicks on the file attachment, the version of MS Word installed on their computer is launched, and a document (.doc) file is opened. The respondent sees a typical MS Word file, yet they only have access to the response fields for entering data. MS Word provides a feature for protecting the text contents of forms. All response fields are highlighted by blue shaded areas on the display screen. The respondent can use the Tab and Shift+Tab keys to move between fields, or alternatively use a mouse to point and click on the field to select it. Information entered consists of an “X” to mark a check box, a specific numerical number for questions that ask for either quantities, percentages, or ordered
rankings, or free-form text to answer an open-ended question. The respondent is instructed to save and name the file, and to return it as an attachment to an email reply message.

**Language Processing (LP) Method for Organizing Main Themes**

The main thrusts of the thesis document were developed by applying the Total Quality Management (TQM) Language Processing (LP) Method [22]. The goal was to develop a cohesive set of themes that incorporated the various types of questions from both the senior manager and project manager surveys. By using the LP method, a consistent thesis architecture was hierarchically generated from the title on down to each survey question. The set of thrusts that were produced provide more insight to the emerging aspects of the research, as opposed to restricting the categorization to the standard choices of performance, cost, schedule, technology innovation, and business process risks.

**Senior Manager Risk Driver Survey Description**

Appendix A contains the senior manager risk driver survey. The survey consists of 19 questions. The questions are a combination of multiple choice, numerical response, and open-ended questions. The responses to this survey remain confidential, even though the instructions did not specifically state this. One of the questions asks the respondent to state what they would have asked if conducting the survey. This question is intended to reveal some focused, riveting questions that can be used in any future work on this topic.

The survey is divided into two major response sections, Preliminary Data and Risk Driver Questions. The preliminary data contains 3 questions for collecting information about the respondent’s type of organization, the respondent’s position, and length of service. This information is for the author’s internal use only. There are a total of 16 questions in the risk driver section. The questions cover project manager experience, technical workforce training, risk identification, risk management responsibility and timing, the respondent’s definition of “appropriate” risk, project prioritization, stability of staffing, the top 3 concerns for project success, and the strongest positive and negative impacts on a project. Also included is a question on any changes or emphasis an organization should make for successfully managing the risks associated with developing future revolutionary systems that integrate the biotechnology, information technology, and physical science disciplines.

**Project Manager Risk Driver Survey Description**

Appendix B contains the project manager risk driver survey. The survey consists of 51 questions. The questions are a combination of multiple choice, ordered ranking, numerical response, and open-ended questions. The survey instructions advise the respondent to select one particular project from their past experience, and base all responses on this particular project. The instructions also state that the selected project should be one which is a challenging, complex systems development. The responses to this survey remain confidential. The response data was obtained with the primary purpose of making a statistical evaluation across a collection of responses that represent a variety of complex systems projects. Like the senior manager survey, this survey also contains a questions asking the respondent to state what they would have asked if conducting the survey, to capture additional questions that will be useful for furthering this topic with any future work. The last survey question provides space for the respondent to provide additional comments in support of any previous survey questions. When provided, this
additional information aids in understanding the basis for a given response to a multiple choice, ordered ranking, or numerical response question.

The survey is divided into 7 major response sections, which include Preliminary Data, Performance Risks, Cost Risks, Schedule Risks, Technology Risks, Organizational/Business Process Risks, and General. The preliminary data section contains 8 questions to collect information about the project manager experience of the respondent, and of the project on which the survey answers are based. The questions probing the specific project seek to identify the project’s type (civilian US government, military US government, or commercial), lifecycle duration, initial budget, size and distribution of the technical development team, and number of enabling technologies used.

The Performance Risks section contains 10 questions designed to collect information on project preparation and planning issues which can have an affect on the performance of the project. Questions probe the use of prior projects, application of prior lessons learned, the implementation of peer reviews, changes to project scope, methods for making technical trades, team confidence, product development approaches, identification of risks, and metrics used to measure project performance.

The Cost Risks section contains 4 questions designed to capture the allocation of funding during the early stages of the project. These questions seek to determine if the project received adequate funding during the preparation and planning phases, and any impacts due to budget instabilities occurring during this part of the project lifecycle.

The Schedule Risks section consists of 7 questions related to meeting the project’s schedule and factors that can jeopardize the completion time of the project. Questions explore schedule slip, the amount of personnel resources the project began with, team member schedule pressure, visibility of master schedule to team members, project contingency time buffer size, number of other projects team members concurrently work, and factors which help to shorten project completion time.

The Technology Risks section contains 6 questions designed to obtain information regarding the enabling technologies selected for use in the project. Questions gather data on key technology risk mitigation strategies, the level of team member understanding for the enabling technologies, the timing of development funding, the influence by other projects on technology selection, and the conducting of peer reviews.

The Organizational/Business Process Risks section includes 12 questions related to how the organization conducts its product development process. Questions probe development team understanding of project objectives and the organization’s strategic plan, the frequency of development team meetings, the level of involvement of key customers/stakeholders, operations personnel, and scientists, the rigor applied to closing project related action items, the level of authority the respondent carried as a leader over the team members, the amount of team member co-location, and the degree of several influences on the product development process. There is also a question regarding views on team staff changes. Since the paradigm of “Faster, Better, Cheaper” has become widely known by many types of product development organizations, a
question was included to obtain the respondent’s view on which constraints drove project risk more than others.

The General section contains four thought provoking questions before reaching the end of the survey. Two questions target the strongest positive and negative impacts on the respondent’s project. The third question asks what the respondent would have asked if conducting the survey. The final question provides space for including any additional comments.

**Common Questions on Both Surveys**

There are four common questions that appear on both electronic surveys. These questions were specifically asked to both types of managers to identify any contrasting views. It was expected that there would be differences in the perspectives between senior managers and project managers over these issues. The common questions are:

1. How well the development team understands how the project specifically relates to the organization’s long term strategic plan
2. The strongest positive impact to a project
3. The strongest negative impact to a project
4. The extent to which the manager believes that engineers are “interchangeable” on development teams (e.g. negligible impact to exchange one mechanical engineer for another during the project’s development, in order to meet the need of another project).

**Data Analysis Techniques**

**Software Technology Used for Analyzing Data**

The SPSS Base 10.0 statistical analysis software program for the PC was used to analyze the quantitative data from the two surveys. The program allows the user to enter the response data into a spreadsheet format, define variables, and define the ranges of possible responses. The software produces statistical information in the form of tables, lists, and various graphical representations such as histograms, bar charts, and pie charts. Superimposing a normal distribution curve over a histogram plot was found to be a useful feature for comparison to a significantly large population. Correlations between two or more sets of data can also be easily generated. Scatter plots with regression lines can be constructed to evaluate the significance of the correlations. All outputs generated by the program can be imported into a word processing document by copy and paste procedures.

**Frequency Distributions**

In order to get a holistic view of the survey data, the frequencies of group responses to each question were evaluated. Frequency distributions provide a good overall picture of the spread across the different choices (classes) of a given question. Questions with evaluated for the predominant number of responses to one or more particular classes. Often it was useful to consider the data in terms of percentages of the total number of responses. Frequency distributions were reviewed by assembling the data into tabular form, histograms, bar charts, and pie charts. Relationships to related questions were also explored to gain further insights. Cross-tabulations were useful for identifying trends in particular segments of the data.
**Correlations**

Correlation between sets of question data were evaluated to measure the strength of the linear relationship between them. Correlation indicates a relationship between variables, but not causality. The Pearson correlation technique was used to observe responses that were statistically significant at the 0.01 level. Scatter plots were generated to examine the pattern of correlation. Regression lines were superimposed over the scatter plot data to facilitate understanding how well one variable behaves with respect to another. The regression lines helped to visually examine the degree of positive or negative correlation. They were also useful for inspecting the degree of linearity since many relationships are actually of the linear form. Close approximations to linear relationships make it easier to comprehend the data, since it would otherwise be difficult to describe in mathematical terms.

Multivariate analysis was also performed to evaluate the relationships among data from a group of questions. Specifically, binary logistic regression was used. Logistic regression is useful for predicting the presence or absence of a particular characteristic or outcome based on the values from a set of predictor variables. It is similar to a linear regression model but is suited to models where the dependent variable has a binary (e.g. yes/no) outcome. The data analysis compared a variety of project parameters to assess their level of influence upon performance degradation, budget overruns, and schedule slippage.

**Potential Sources of Error**

Despite the noblest of attempts by a researcher, potential sources of error are always present. Having an understanding of the possible error sources aids the reader in comprehending the thesis research results with the proper level of confidence. Because the research methodology includes the sampling of manager populations by the use of survey questions, there is always the chance that the context of a question was inadvertently misunderstood. Attempts to prevent this situation from happening were conducted wherever data was thought to be confusing. Clarifications were made during in-person interviews, and by additional efforts to contact the respondent by telephone or email to resolve the ambiguity. Another potential source of error occurs when a question contains a response that is incomplete or absent entirely. In these cases, the question was flagged and removed from all types of analysis. Yet another error source exists if the respondent data is inaccurate in any way, e.g. because a numerical response is drawn from memory, or an answer is subjective due to the respondent’s particular viewpoint. Since all surveys are exposed to this risk, the data supplied by all respondents is assumed to be accurate enough to meet the needs of this research effort.

**Literature Sources**

Relevant programmatic risk identification, assessment, and management concepts learned while attending the MIT System Design and Management (SDM) Program were applied in the development of the electronic survey questions, for generating the discussion topics during in-person interviews, to analyze the qualitative and quantitative data, and to suggest some organizational strategies for implementation. The latest pertinent findings from MIT course books, readings, case studies, and ongoing academic research at MIT, was used in support of these concepts. Specific SDM courses that proved useful for supporting the research include: Engineering Risk Benefit Analysis, System & Project Management, Systems Engineering, Systems Architecture, Managing Technology Innovation, Technology Strategy, Strategy & Organization, and Operations Management. Official reports made available to the public, which
include the December 2000 NASA Integrated Action Team (NIAT) Report, the NASA Mars Mission Failure Reports, the November 2000 National Reconnaissance Office (NRO) Commission Report, the U.S. Air Force Science and Technology Workforce Report, and Defense Advanced Research Projects Agency (DARPA) Reports provided valuable insights for identifying the critical risks facing organizations today that develop revolutionary complex space systems, and in formulating useful strategies for the future.
Chapter 3

Risk and its Management

The goal of this chapter is to provide the reader with a background on risk and its management. The first section examines several current risk theories from well known literature sources from academia, industry, and government practice. The definitions of risk, "acceptable" risk, and risk management are explored. The different types of risk are also discussed, including those which this research focuses upon. Several concepts for effective risk management are also introduced. The second section presents the interview perspectives on what drives risks in complex space systems, from three of the NASA Enterprises. These perspectives were studied to obtain a feel for how risk varies across the agency. The third section is a discussion on the public perception of risk. How the public views the consequences of a space mission failure is compared to other common failures faced in daily life. Public perception has had a bearing on how NASA conducts itself. The chapter concludes with a summary of key findings.

What is Risk?

Risk is sometimes defined with a negative connotation, posing it as only the possibility of suffering harm or loss [6], or focusing on the downside of a project [20]. Other definitions consider risk to include the possibility of a gain as well as a loss. Risk can also be defined as a threat to success [8]. Alternatively, risk is considered a measure of the probability of an unsatisfactory outcome times the loss occurring from such an outcome [12]. The probability of a given outcome is typically quantified by assigning a value between 0 and 1. A consequence which has no possibility of occurrence is regarded as having a probability equal to 0. Similarly, a consequence which is certain to result from a risk is regarded as having a probability equal to 1. Fractional values in between 0 and 1 represent the expected degree to which a risk will yield a given consequence. Risk is also seen as an indication of the degree of variability in the outcome or result of a particular action [16]. System risk denotes the combination of the likelihood of various outcomes and their distinct consequences, focusing on the undesired outcomes.

Within the scope of a project, risk is considered the measure of the potential inability to achieve the goals of a project while remaining within its defined cost, schedule, and technical constraints [3]. It consists of two components: the probability of failing to achieve a particular outcome, and the consequences of failing to achieve the outcome. Stated in a slightly different way, risk is commonly viewed as the uncertainty that can occur during the execution of every phase of a project which can have a significant negative impact on the performance, schedule or cost of the project [27]. Taking a more encompassing viewpoint, risk is any concern that might adversely impact a system.

For the purposes of this research, risk is defined as any project-related activity which can negatively affect the outcome of a project in terms of its performance, safety, cost, or schedule. Any technical, managerial, or political actions which can levy a negative influence on the project are considered risks.
What is “Acceptable” Risk?

Accepting risk is considered one form of responding to the presence of risk [6]. Acceptable risk means that the project accepts the consequences if the threat materializes. Alternative to accepting risk, a project could exercise risk avoidance or risk mitigation. Risk avoidance eliminates the existence of the threat by eliminating its cause. However, note that not all threats can be eliminated. Risk mitigation reduces the probability of occurrence of the threat, and/or selects alternatives which serve to devalue a negative outcome. A popular space system example of risk mitigation is to incorporate a redundant system should one fail during operation.

Acceptable risk is also viewed as the level by which the responsible project manager has the authority to accept without further risk mitigation actions required [8]. Acceptable risk can vary with the type of mission. Acceptable risk should be determined at the onset of a project, so that all requirements can be developed accordingly. Acceptable risk is not a project attribute that is decided later downstream in a project lifecycle.

The NIAT report defines acceptable risk to be the risk that is understood and agreed to by the program or project, the governing program management council, and the customer as sufficient to achieve defined success criteria within an approved level of resources [13].

For the purposes of this research, acceptable risk is defined as the level of risk which all responsible individuals of a project willingly accept, and ascertain is worth facing the potential consequences for the pursuit of the defined project benefits.

Types of Risk

The Project Management Institute [6] states that there are internal and external types of risks. Internal risks are those which the project team can control or influence, such as staff assignments or cost estimates. External risks are those beyond the control or influence of the project team, such as market fluctuations or government actions. The NASA System Engineering Handbook [16] claims that traditionally, risks have been divided into the broad categories of cost, schedule, technical, and safety/hazard risks. Recently, additional categories have been added, which include organizational, management, acquisition, supportability, political, and programmatic risks. These newer categories reflect the additional concerns of NASA project managers and system engineers operating in the current agency environment.

Smith and Reinertsen [23] segments risk into just two categories, technical and market risks. In this context, technical risk is the probability of failing to achieve the performance, cost, or schedule targets of the project. Market risk is the probability of the product not meeting the needs of the market.

Browning [2] defines six specific types of product development risks in his dissertation, performance risk, schedule risk, cost risk, technology risk, market risk, and business risk. Performance risk is the uncertainty in the ability of a design to meet desired quality criteria and the consequences thereof. Schedule risk is the uncertainty in the ability of a project to develop an acceptable design within a given span of time and the consequences thereof. Cost risk is the uncertainty in the ability of a project to develop an acceptable design within a given budget and the consequences thereof. Technology risk is the uncertainty in a capability of technology to provide performance benefits and the consequences thereof. Market risk is the uncertainty in
the ability of a project to develop an acceptable design within a given span of time and the consequences thereof. Business risk is the uncertainty in political, economic, labor, societal, or other factors in the business environment and the consequences thereof.

This research focuses on programmatic risks, defining them into six specific types addressed by the questions on the project manager risk driver survey. These programmatic types include performance, cost, schedule, technology, organizational, and general risks. Performance risks include those project activities which can negatively affect the technical performance of the complex system, or the safety to either the operator(s) or to the equipment, facilities, or surrounding environment. For human space flight missions, astronauts are viewed as the operators. Cost risks include those project activities which can negatively affect the project meeting its initially targeted budget. Schedule risks include those project activities which can negatively affect the project meeting its originally defined completion date. For complex space systems, the completion date is synonymous with the launch date. Technology risks include those project activities which can negatively affect the successful infusion of the technologies which enable the mission. Organizational risks include those business functions performed by the organization which can negatively affect the outcome of the project. General risks are those other risks which did not fall into one of the previous categories.

What is Risk Management?

According to Conrow [3], risk management is the act or practice of dealing with risk. It includes planning for risk, the identification and analysis of risks, the determination of risk handling options, the continuous monitoring of risks to observe their changes over time, and the documentation of the overall risk management program. Risk management is concerned with the outcome of future events, whose exact outcome is unknown, and how to deal with these uncertainties. A good risk management process is proactive in nature and is fundamentally different than crisis management (problem-solving), which is reactive.

Greenfield [10] states that risk management is a continuous process which identifies risk, analyzes risk and its impact, prioritizes risk, develops and implements risk mitigation or acceptance, tracks risks and risk mitigation plans, and assures risk information is communicated to all project/program levels. The Project Management Institute [6] adds the fact that risk management defines enhancement steps for opportunities as well as responses to threats, and defines responses to changes in risk throughout the duration of the project. The NASA System Engineering Handbook [16] describes risk management as the purposeful thought to the sources, magnitude, and mitigation of risk, and actions directed toward its balanced reduction. Further, risk management is an integral part of project management, contributing directly to the objectives of systems engineering.

Figure 3.1 illustrates the differences that result when risks are managed versus leaving it unmanaged [23]. The key to managing risk is in controlling the probability of occurrence. The goal of risk management is to either eliminate or to drive down the probability of occurrence to an acceptable level. In the top set of graphs, we see that without managing the amount at risk, the probabilities of negative occurrences remain present over time, resulting in an increasing level of risk to the project. The bottom set of graphs show that risk mitigation steps will decrease the probabilities of negative occurrences, resulting in a level of risk which is at or below a critically defined threshold.
The risk categorization scheme used in the past by the NASA Space Station program can lend some insight into the value of risk management. Figure 3.2 illustrates the probability of occurrence for a negative outcome versus its impact of the consequence to the system. This risk matrix shows that risks with higher probabilities of occurrence that pose a sufficient impact to the system must be mitigated. Note that for risks that have a high probability of occurrence but pose little or no threat to the system, no action may be required. By the same token, risks that can significantly impact the system but have a probability of occurrence below what is deemed acceptable, may also require no further action.

For this research, risk management consists of the proactive steps that can be performed early in a project’s lifecycle, namely the preparation and planning phases, in order to increase the probability of a complex space system successfully meeting its performance, cost, and schedule goals.

**Some Concepts for Effective Risk Management**

Complex system product development has been described by Browning as an exercise in risk management. Risk is inherent because it is brought about by the uncertainty regarding product performance in the marketplace, and the ability of the development process to deliver the product within a given schedule and budget. It also stems from the consequences of undesirable
outcomes. One can consider the product development process to be a process of uncertainty reduction and risk management. Bettering our understanding of the sources of risk in the product development process is fundamental to its improvement. A key to risk management consists of identifying the main contributors of uncertainty. It is then necessary to explore the relationships between sources of uncertainty, to discover how one risk affects another. Effective risk management requires continuously monitoring project risks and the use of control mechanisms for identifying and reacting to system instabilities. A system view is needed so that risk management actions reduce overall risk to the system instead of pushing risk into yet another category. Understanding the relationships between identified risks can assist in determining the system points of highest leverage.

The NASA Systems Engineering Handbook concurs with the requirement of a systemic view of risk. When a risk is determined to be unacceptable, risk analysis and mitigation are performed to identify alternatives that will reduce the impact of the risk. Risk mitigation is a challenge because efforts to reduce the effect of one risk may in fact increase the effect of one or more other risks. Therefore, it is crucial for the project manager to understand the systemic effects of risk mitigation strategies in order to make sound decisions. Since uncertainty is a fact of life in complex systems development, the project manager must use a disciplined approach to effectively manage risk.

Greenfield complements the discussion by pointing out that effective project management depends upon a thorough understanding of the concept of risk, the principles of risk management, and the establishment of a disciplined risk management process. Increasing system complexity, increased competitive pressure, reduced development budgets, and shorter product development cycles are exposing the inadequacy of managing risk by non-rigorous approaches. In order to develop the highest quality complex systems, strong discipline, accurate documentation, faithful reporting of any and all anomalies, independent reviews of all steps and decisions, and extraordinary attention to detail are required. Also, risk management should be considered by working-level team members every day as part of their job function. Although not every employee should become a manager of risk, it is important enough to be considered and performed by all personnel involved with the project.

According to Conrow, risk management must be effectively integrated with other critical high-level processes, e.g. project management and systems engineering, as well as with lower-level processes, e.g. cost analysis, design, schedule tracking, etc. A fundamental shift in the attitude of senior and project managers from reactive problem solvers to proactive risk managers is needed. In the past, management sometimes viewed risk as something to be avoided. A project which contained risk was subject to intense review and oversight. Nowadays, the attitude must be different, since managers in the DoD and NASA realize that risk is inherent with every program. It is now necessary to analyze future project events to identify potential risks and take appropriate measures for their control.

Rechtin [19] recommends that if being absolute in defining system risks is impossible, then be relative. Ideally, the greatest risks are attacked first, and the lesser ones are left until later. The greatest mistake is to begin with the easy ones and generate the illusion that progress has been made. Until the most significant risks are proven they can be overcome, the project is not on a
path for success. Highsmith [12] supports this notion by saying that if risk management is restricted to dealing with those smaller risks that can be mitigated by quick action, a project confronts all of the risks except the ones which really matter. Smith and Reinertsen [23] agree by pointing out that product development performed on ambitious time frames requires starting with the toughest risks first. Since the higher risks usually fall on the critical path, they must be dealt with up front. The project manager must help the team overcome the natural tendency to focus on the easier risks first. The mere number of team accomplishments in a given period must not be rewarded over the successful mitigation of the fewer, more challenging risks. Good risk control systems keep the toughest risks highly visible. Because there is less time to react in projects with ambitious schedules, and the cost of fixing a problem discovered early is much less than if caught later in the lifecycle, early warning systems in potential risk areas are crucial. Continuous management attention helps in this regard.

Smith and Reinertsen claim that the key to managing risk is to deal with it before problems occur, i.e. manage it proactively. An important byproduct of effective risk management is that developers start to assume the responsibility for risks. Conrow supports this theory by citing that the longer it takes for problems to surface in a project, the fewer options there usually are to resolve them. Browning feels that the proactive management of risk will become the critical operational paradigm of business for the early 21st century. Ulrich and Eppinger [26] believe that the explicit identification of risks during the project planning phase helps to minimize the number of surprises the team will have to communicate to senior management later in the project lifecycle. After the project team identifies each risk, they should assess the level of each risk, and then specifically determine what actions the team will take to minimize each risk.

Rechtin perceives good project managers to possess the ability to properly categorize risk components and elements, so that available resources can be most effectively allocated. Highsmith believes that project managers should become risk entrepreneurs, using risk management as a competitive tool. Rather than managing or ignoring risk, the risk entrepreneur should use uncertainty to attack the situation. Smith and Reinertsen emphasize the need for effective risk communication by the project manager and the project team members. The communication of potential problem areas must be kept open horizontally as well as vertically. If project developers are discouraged from communicating problems, solutions are not likely to be formed.

Some keys for performing good risk identification include [27]:

- Surveying program participants for potential concerns based on experience and knowledge in their respective disciplines
- Conducting brainstorming sessions within each product team to surface concerns
- Analyze requirements and resources for implementation concerns
- Analyze customer statements which indicate the customer's anxiety in selected areas
- The use of a structured process to identify risks
- Grouping risks into risk categories based on the risks themselves, as opposed to predetermined categories
- Identifying cause and effect relationships within and between categories
- Writing clear and quantifiable risk statements
Some conventional wisdom for best practices in risk management:

- Everyone on the program is responsible for risk management
- Each mitigation action should have an individual assigned to ensure it is done
- Make risk management an ongoing priority
- Know the project environment as well as its requirements
- Bring the right expertise to the risk management process
- Look at ALL risks
- Examine the relationships among risks

**NASA Interview Perspectives on What Drives Risk**

**Risk Management Perspectives for Human Exploration & Development of Space Missions**

The unitary attitude for human space flight is that there is NO room for failure. Failure is just not an option. Safety is the number one issue, and is the clearly publicized hallmark of NASA. This position drives a culture that no failures whatsoever are tolerated, even early in the development process. This culture generates considerable employee pressure to advance a project through its early stages successfully. Project success was cited to be dependent upon:

1. An integrated product team consisting of cross-disciplinary membership
2. The mandatory inclusion of operations personnel
3. Team members that envision the end product early and capture those thoughts on paper

To practice effective risk management, there has been a thoroughly disciplined structure developed over the years of human space flight. There is considerable cross-checking of each other's work. The team must be kept together end-to-end...this is known as “Design for Support,” not “Support for Design.” The space shuttle program has clearly identified its top goals, for which the characteristics of the first two are met by effective risk management. The first and foremost goal is to fly safely. To fly safely, it is envisioned that the development of reliable hardware, the existence of excellent teams, and the discovery of problems before they occur will be necessary. The second top goal is to meet the shuttle manifest. This is comprised of flying on schedule, achieving 100% mission success, and exhibiting flexibility and responsiveness to manifest and mission problems.

When the issue is raised of whether Faster, Better, Cheaper applies to human space flight missions, the attitude is that you don’t want a “K-Mart” version of the Space Shuttle. One doesn’t want to insert more risk than is already present to manage. When there is a change to successful practices (the implementation of FBC in the HEDS Enterprise is viewed as such), there must exist the capability to manage the new risks that are generated as a result.

Robotic spacecraft missions are used to applying resources on more of a linear scale (e.g. adding N units of cost to obtain M units of performance). For human space flight missions, resources must be applied in a non-linear fashion to achieve a risk tolerance that approaches zero. These approaches are certainly not the most cost-efficient methods. Thus, a connection to FBC is not apparently perceived.

The use of lessons learned has been well practiced for human space flight missions. Employees share lessons learned effectively in a less formal atmosphere. Several options
include “Lunch & Learn” seminars, Engineering Colloquia Series, and conversations at the water-cooler. However, there is a concern over the changing role of the civil service engineer. The agency is losing too many experienced personnel, and not capturing their knowledge before they leave. Wholeheartedly, there is believed to be no substitute for experience in this type of business.

Risk Management Perspectives for Earth Science Missions

The Earth Observing 1 (EO-1) mission proved to the Earth Science Enterprise that there is substantial value in reaching a common understanding for a mission’s risk profile. The EO-1 spacecraft was designed to test breakthrough remote sensing technologies for the advancement of Earth Science. Due to a lack of clearly stating the desired risk posture for the mission at project inception, EO-1 was found to move toward a lesser risk tolerant position as the launch date approached. The influence of the recent Mars mission failures, coupled with several development problems which increased both cost and schedule, the project found itself rethinking the mission success criteria prior to launch. By attempting to change the mission’s risk profile late in the development lifecycle, valuable lessons were learned regarding clearly stating and reaching a common understanding of a project’s risk posture.

The definition of Faster, Better, Cheaper is in the eye of the beholder. These parameters are considered to be relative to what you compare them to. There is no substitute for success; this was learned from the recent Mars missions. The Earth System Science Pathfinder (ESSP) program may have reacted too quickly to the external transfer of responsibility desired by FBC. Mission success responsibility was transferred to an external organization (a university) despite them lacking an appropriate risk management infrastructure. NASA did not recognize the risks that were being taken due to insufficient university oversight. NASA is still responsible for the mission despite any lack in capability by the selected external institution.

In the 1970’s and 1980’s NASA had a good success record working with contractors. There were experienced project managers who were skilled at developing relationships with contractor organizations, which resulted in a partnership that yielded successful results. Problems began to occur as the agency vastly increased the number of projects in concert with a declining experience base, resulting in the remaining talent being spread too thin. To further compound the issues, there has been a hiring and training impediment which has caused a loss of intellectual capacity in the agency over the last decade. An employee can be as smart as a whip, but this business cannot be learned without first experiencing how to do it right. Quality project managers are grown, not born.

Risk for the Earth science vision is somewhat defined. The Enterprise risk posture changes from risk averse for operational missions (e.g. GOES, POES), to more risk accepting for exploratory missions (e.g. GRACE, Cloudsat). The overarching attitude is of risk-averseness, but the key is that this is an unforgiving business that must be well understood, with engineering due diligence strictly practiced. The present Earth science focus is on Science, the Instruments, and the People. The Enterprise also needs to find a means for inexpensive access to space.
Risk Management Perspectives for Space Science Missions

Mars Exploration missions took huge risks with inexperienced people. Corner were also cut regarding testing. The Mars Polar Lander error is believed to be found only through extensive testing. Mars Climate Orbiter was a result of an ineffective data transfer between government and contractor organizations. In retrospect, some are skeptical about whether a review could have caught that type of error.

Standard project reviews should not be counted on as the mechanism for finding the problems inherent in the system being developed. It is rare that a standard review actually finds anything wrong. The value of the standard review process rather lies in the actual preparation for this checkpoint by the development team. It gives the team the opportunity to review and document what has happened. The need for independent reviews seem to be primarily the mindset of senior management. However, some believe that peer reviews are better at finding more hidden problems. When peer reviews are used, they are more effective at uncovering problems when performed at the sub-system level as opposed to the systems level. In most of the past failure cases, extensive reviews would not have uncovered the problem and prevented mission failure. One exception was the NASA WIRE mission, which was implemented under FBC. The success of a project is far more dependent upon having an experienced team than it is on the review process.

“Acceptable” risk should be defined within the context of the level of redundancy that makes sense. Redundancy is expensive, it adds mass, and requires additional time for development and testing. In comparing the Cassini mission to Lunar Prospector (LP), LP was a single-string spacecraft exhibiting a sound architecture. Thus, the LP architecture was deemed acceptable risk. On the other hand, due to the radiation exposure, distance traveled, and expected lifetime, the Cassini spacecraft required considerable redundancy to ensure success. A single-string architecture wouldn’t be sufficient for a seven year journey to Saturn. Mars Odyssey contains single-string avionics for Mars orbit insertion – this was considered acceptable risk with the inclusion of proper testing. Similarly, the Titan IV launch vehicle does not carry dual-redundant systems.

FBC was not meant to mean single-string architectures. This was an assumption by spacecraft developers. Risk management is needed to identify the areas of the spacecraft where both single-string and redundancy makes the most sense. Tight budgets also do not mean single-string architectures. No failure is a bargain! The NEAR spacecraft built in some redundancy to gain robustness. This robustness was enough to survive several close calls. NEAR was a successful FBC project because it strategically made use of redundancy while maintaining some single-string areas of the spacecraft.

The only way to operate successfully when there are so many ongoing projects is by the use of a matrix organization. There is tremendous value gained by housing together the same disciplines and sharing ideas and experiences. Under this type of setup, it becomes a significant responsibility of the functional manager to sensibly trade the deployment of personnel. It should be a rare event to pull someone off of a project. Doing so destroys an engineer’s level of personal commitment, as most NASA engineers are extremely proud of their work.
Projects not as high on the priority list as others suffer at times due to resource allocation. However, the public doesn’t cut NASA any slack nonetheless. Although it will never happen, the priority #1 projects need to mentor the lower priority projects.

Public Perception of Failure

The NASA Administrator posed two interesting present day examples of acceptable technology performance failure, during his Distinguished Lecture at MIT in October 2000. A majority of people use cell phones today on a regular basis. Cell phones frequently fail during use, e.g. loss of a connection, unable to establish a network, poor signal quality, etc. People seem to be willing to tolerate these problems, possibly because they do help to make our life easier, or maybe because they are just nifty gadgets. Similarly, poor quality in American automobiles was tolerated in the 1970’s until Japan came to the market with superior quality models. Further, many people own a portable computer today. A predominate number of them run the Microsoft Windows operating system. Those have all experienced problems when using Windows at one time or another, including a temporary computer “crash” during the worst of times. However, it is accepted as part of the present technology today and tolerated, with the hope that improvements will be made in the near future. However, there are no guarantees that these improvements will arrive at any given time. Yet for space flight, people expect the latest missions to be always successful without any glitches. That is a tall order considering the magnitude and complexity of the endeavors, and in most cases, the fact that such a venture hasn’t ever been tried before. If an established operating system can still generate unusual failures after years of customer use and feedback, how can the public realistically expect NASA to be always successful in attempting radical things for the first time?

One interview respondent had this following useful perspective: When individuals are in school, getting an exam grade of 96 out of 100 is considered an A, and is quite impressive since it is nearly a perfect score. In contrast, when the Challenger disaster occurred, the Space Shuttle success rate became 24/25, the same percentage. However, the public views these two equivalent ratings of performance much differently. Part of it may be due to the exam being judged more as a one-time event, while Shuttle launches were becoming considered almost routine to the public eye. This suggests that people get accustomed to demonstrated success very quickly, but react to failure without any tolerance. If the Space Shuttle didn’t have such a successful track record up to that point, one can wonder if the view of the Challenger disaster would have been more readily accepted by the public. Further supporting this notion, consider the public acceptance of risk for the Challenger disaster versus an automobile crash while driving. Astronauts knowingly accept the risks of space travel, and even though the job is clearly an extreme risk, the public reacts dramatically when there is an accident. On the other hand, car crashes occur every day killing up to 7 people or more. As a normal part of life, people accept the consequences that result from this risk.

Rechtin [19] discusses a relevant example regarding the safety of Department of Energy nuclear reactors. The Nuclear Regulatory Commission must continue to diligently reduce risks, so that the public will be convinced that reactors are safe. In doing so, the engineering task is to design reactors whose safety is so transparent that even the skeptical elite is convinced. It is then that it is expected the public will be convinced.
Highsmith [12] uses the sport of mountain climbing as a good example of personal risk management. To one unfamiliar with the sport, mountain climbing appears to be a very risky undertaking. However, the vast majority of climbing activity is reasonably safe, due to the fact that experienced climbers understand the specific risks and make significant efforts to keep them under control. In most of the mountain climbing accidents, the injured are inexperienced people without proper skills or training. These individuals are unaware of the true risks and do not know how to successfully manage the risks by using proper equipment and training. When an experienced climber takes a bold risk on a mountain, he/she does so with an understanding of the situation. The choice to go ahead is an informed one.

**Summary of Key Findings**

Risk can be defined in numerous ways. All of the definitions border on some measure of a project not meeting its goals or experiencing some form of negative outcome. There are not as many published definitions of acceptable risk available. Generally speaking, acceptable risk is that level of risk for which the project has been determined to proceed, as agreed upon by all responsible parties. Different authors categorize risks into a variety of types. Segmenting types of risk into the categories of technical, programmatic, and market risks comprehensively cover all of the types found in the literature sources. Risk management is the practice of dealing with risk. Expert sources emphasize the need for a continuous process, and proactive steps early in the life of a project to ensure success. Effective risk management for complex systems development requires a systemic view in order to evaluate the interrelationships between known risks, before settling on the control approaches. Effective risk management also requires rigor and discipline by the project manager and the project team members throughout the entire lifecycle. A fundamental shift in attitude from being reactive to becoming proactive, is necessary as projects increase in complexity while being driven to shorter completion times.

The NASA Space Science, Earth Science, and Human Exploration and Development of Space Enterprises all identify well-qualified, cross-disciplinary teams as an essential ingredient for success. Human space flight has developed sound risk management strategies by evolving them over the years, in addition to the ample use of lessons learned. The space science and Earth science missions can likely benefit by the cross-fertilization of some of the risk management techniques used in human space flight. The space flight business, independent of the particular Enterprise, requires experienced personnel that develop only over time working on NASA missions. There is no substitute for experience. No academic institution can teach a person this business in the classroom. The loss of personnel throughout the agency is affecting all of its Enterprises.

FBC for human space flight is not a concept that appears to be presently well understood within the thrusts of the Enterprise. FBC for Earth science missions means a relative improvement in cost, schedule, or performance, such that success is not compromised. FBC for space science missions means a focus on cost and schedule efficiency without the premature elimination of redundancy. It has been demonstrated that the use of single-string architectures must be employed diligently in planetary spacecraft. The NIAT report acknowledges that there is no current delineation between FBC and non-FBC projects at NASA. It further asserts that the need to do so is not present because the goal is to strive for the reduction of mission risk without compromising safety considerations. Instead, the NIAT recommends adequate guidance for risk decision-making. Greenfield [10] states that reliability is approximately the same between
flagship spacecraft and FBC spacecraft, but for different reasons. Large, complex spacecraft have more funding available for risk avoidance, but more things can go wrong. Simpler FBC spacecraft allow for better system comprehension and more informed risk trades.

Figure 3.3 attempts to provide the reader a feel for some of the differences in risk drivers among the missions from the three NASA Enterprises. As a cautionary note, the figure is meant to represent only some of the missions from each Enterprise. Since each Enterprise has a wealth of diverse missions on its agenda, it is impossible to make a one-size-fits-all representation. We that for Earth science missions, cost is perceived to be the largest risk driver. The Earth science vision has emphasized frequent, affordable access to space as the key to achieving its goals. Performance is perceived as the next largest driver, since interactive networks of space-based and ground-based observatories, microsatellite constellations, and other infrastructures will attempt to yield uninterrupted, global coverage. At present, schedule is considered the smallest risk driver. Over the next several decades, it will take many missions to similar Earth orbits to complete the initial construction of these networks, and to refurbish aging assets already deployed. This will provide some deployment flexibility for a given mission.

![Figure 3.3 Performance, Cost, and Schedule Risk Drivers for Different NASA Missions](image)

For space science missions, the example of a Discovery mission spacecraft is assumed. Cost is considered the largest risk driver, as Discovery class missions are constrained by a cost cap from the onset. Schedule is perceived the secondary risk driver, since a celestial body encounter is often dependent upon a launch window of opportunity, driven by a unique alignment of the planets to achieve a closest approach, a gravity assist, etc. Performance is considered the smallest risk driver because the performance goals are expected to be set commensurate with the cost and schedule constraints. For human space flight missions, the space shuttle is used as the example. Performance is the uncontested primary risk driver, since performance in this context includes crew safety and the safety of the surrounding launch environment. Schedule is the
secondary driver. There are many interrelated activities involved with meeting a particular launch day, and any slip to the launch schedule impacts these activities as well as the missions which follow in the manifest. Cost is the smallest risk driver, because a set price cannot be placed on safety. Discussion from earlier in the chapter identified the considerable costs that result due to the non-linearity of driving toward a risk tolerance of zero.

Acceptable risk in many cases depends upon what the track record is. Without any failures, an organization can be perceived as too conservative – not on the cutting edge. Some failures show the world that the envelope is being pushed, and that the endeavor must be worth doing. The NIAT report suggests that the approach to missions should not be risk-averse. Acceptable risk must be based on outcomes, not outputs. Alternatives must be determined and enforced when it makes sense to do so.

The NASA employees feel that the agency has done so much for so little for so long, the public has taken it for granted. NASA missions need to be framed to the public in a way which will perceive value such that its risk will be considered acceptable. The public should view risks as eventual gains, not just as potential losses. The DARPA model accepts failure completely as long as the payoff for success is high enough. Modern negotiation theory [1] suggests that people are generally risk-averse when they are confronted with potential gains. On the contrary, they are risk-seeking when confronted with potential losses. This seems counterintuitive. Congruent with this theory, NASA may need to emphasize the likelihood of failure more often to the public, instead of exhibiting the level of confidence that it has done so far in history. Framing the mission endeavor in this way may very well help in relaying the message to the public that what was learned through failure is definitely a gain in terms of space flight progress.

Rechtin [19] claims that complex systems are faced with the special problem in achieving a no-risk posture. Experience has shown that a nonscientific observer questions the validity of risk estimation. For unknown reasons, perceptions of risk differ widely even from clearly proven risks, e.g. the probability of death due to smoking, car accidents, street violence, etc. Behavioral scientists have convincingly demonstrated that human intuition about risk is incorrect most of the time. Yet it is the perception of risk that determines an individual’s behavior. These perceptions determine whether a person supports or opposes a particular event. Thus, “Risk is defined by the beholder, not the architects of the system.” The way to achieve mutual agreement is by sharing the risks, as perceived by the parties concerned. Independent of its practicality, sharing risks elicits fair treatment to perceptions and exercises social cooperation.
Chapter 4  
Attitudes Toward Risk Management

This chapter studies the responses of senior managers and project managers to a group of survey questions which probe their attitudes toward risk management. The questions include topics such as: who should take primary responsibility for risk management; which lifecycle phases that risk management practices should be emphasized; prioritizing projects in an organization; projects developed under the paradigm of Faster, Better, Cheaper; successful approaches and challenges to the product development process; approaches to shorten a project schedule; and perceptions due to insufficient funding.

Responsibility for Risk Management

Senior managers were polled to determine who they feel is primarily responsible for a project’s risk management. The reader may refer to question R2 of the survey in Appendix A. Table 4.1 provides the most popular responses.

<table>
<thead>
<tr>
<th>Primary Responsible Party</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>The project manager</td>
<td>76.2%</td>
</tr>
<tr>
<td>The project team members</td>
<td>14.3%</td>
</tr>
<tr>
<td>The Reliability &amp; Quality Assurance (R&amp;QA) Group</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

Table 4.1 Risk Management Responsibility

Over 76% of the respondents selected the project manager. This response is in agreement with one interview respondent’s view that “The essence of risk management is project management.” The response rates of some of the alternative choices are worth a bit of discussion. No one selected the choice of “stakeholders during peer reviews,” or “equally among everyone involved with the project in some way.” Approximately 14% of the respondents chose the project team members. It defied expectations that the choice of “Reliability and Quality Assurance Group providing oversight” did not achieve a much higher response rate than 4.8%. A single respondent stated that the chief engineer assigned to the project has primary responsibility. For projects of enough size and/or importance to afford a dedicated chief engineer, this appears to be an attractive method for handling risk management. It is more likely that the chief engineer can be more focused on this aspect of the project than the project manager realistically can afford given his/her other responsibilities. According to Smith and Reinertsen [23], ideally all those involved with the project in some way should maintain some level of responsibility for risk management. Also, a Futron Corporation study [8] recommended that risk management must be part of everybody’s job. Current organizational policies lean toward risk management practiced as a separate discipline, which can be a setup for failure. Today’s complex system risks are counter-cultural and non-integrated, requiring group involvement.

However, senior management prefers a single person to consistently communicate with. One interview respondent felt that the project manager provides the programmatic and technical oversight, while everyone else associated with the project should feel accountable for risk management. From another senior manager’s perspective, “The buck stops with the project manager.” A third interview respondent felt that the project manager cannot delegate his/her
responsibility for risk analysis. The project manager can get support if needed, but cannot
delegate this work to someone else. Evidently, there are a variety of management perspectives
for risk management responsibility. The NASA Systems Engineering Handbook states that
proper risk management requires a team effort. All of the team members as well as managers at
all levels must be involved in some way. However, it continues to say that risk management
responsibilities must be assigned to specific individuals.

Project Phases to Emphasize Risk Management Practices

Senior managers were asked to select the project phases which obvious steps in risk
management should primarily be emphasized. The reader may refer to question R3 of the survey
in Appendix A. Figure 5.1 illustrates a plot of the percentage of respondents emphasizing risk
management steps for each project phase. It is observed that the predominate phases are
planning and design. Although the respondents largely agree (71.4% of the time) that the
preparation phase should stress risk management practices, it is not the foremost phase. There is
a declining percentage of emphasis as the project lifecycle progresses, as observed by the values
for the development and operations phases. The magnitude of the values for these two phases
indicate that risk management practices are still quite important to emphasize, however not as
much relative to the earlier phases. It may be fair to assume the perception to be that proper risk
management emphasis earlier in the lifecycle will allow for less emphasis later. Theoretically,
the plot should be approximately linear with a declining slope, such that the highest percentage is
in preparation phase and the lowest percentage is in the operations phase. The Futron
Corporation study recommends fully integrating risk management into all appropriate phases of
the project lifecycle. Greenfield’s notion of continuous risk management suggests a sustained
emphasis throughout the entire lifecycle.

![Figure 4.1 Risk Management Emphasis by Project Phase](image)

Prioritizing Projects Across Standard Measures

Senior managers were sampled to determine how valuable they would find having the ability
to prioritize their organization’s projects according to schedule, performance, cost, scope, and
innovation. The reader may refer to question R7 of the survey in Appendix A. The motivation
behind asking this question was to assess whether creating a mixed portfolio of projects, where
priorities could be assigned according to differing objectives, could help an organization manage
its many ongoing activities more effectively. Over three-quarters of the respondents (76.2%)
claimed this approach is either extremely or very valuable. Interestingly, no respondent found it rarely valuable, but one respondent did find it not valuable at all. The highly favorable response to this approach begs the question, why aren’t organizations implementing such a strategy more often?

Organizations are likely to benefit from this approach. By first determining the relative priorities of their projects according to these parameters, it would be easier to make hard decisions on project requirements, acceptable risks, changes to scope, and the like. It makes it easier for senior management to identify the key risk drivers for each project. If an organization aims for a balanced portfolio of projects in this regard, then they will not have to bank the success of all of the projects upon the same risk profile. It may also alleviate multiple projects from competing over the same types of resources. As an example, consider the two NASA mission scenarios in Table 4.2. We see that for a Space Shuttle mission, performance (including safety) is of the highest priority. The schedule is of high priority because of the intricacies of keeping the Shuttle manifest schedule on track. There are so many interleaved tasks that are affected when a schedule slips. Therefore, schedule is considered a higher priority than cost. Cost is a much lower priority than performance because for human space flight, economy can not compromise safety. In the case of the Discovery Spacecraft mission, cost is the highest priority, and usually set by a cost cap. The schedule is of high priority, since it is likely that the science investigation is tied to some celestial condition, such as the orbital position of a planet to take advantage of a gravity assist. The performance is of lowest priority of the three parameters, and would take the hit in order to meet the cost and schedule constraints.

<table>
<thead>
<tr>
<th>Priority Level</th>
<th>Low</th>
<th>Med</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Space Shuttle Mission</strong></td>
<td><img src="image" alt="" /></td>
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<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>Performance (including Safety)</td>
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<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>Schedule</td>
<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>Cost</td>
<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td><strong>Discovery Spacecraft Mission</strong></td>
<td><img src="image" alt="" /></td>
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</tr>
<tr>
<td>Performance</td>
<td><img src="image" alt="" /></td>
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<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>Schedule</td>
<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>Cost</td>
<td><img src="image" alt="" /></td>
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</table>

Table 4.2 Comparison of Two Different NASA Missions

**Perspectives on the Faster, Better, Cheaper (FBC) Paradigm**

Project Managers were polled to obtain their viewpoints on the prevailing risk drivers to a project implementing the Faster, Better, Cheaper approach. At a minimum, aerospace and aeronautical organizations outside of NASA are familiar with the approach, and some are likely to be implementing approaches that are similar in some respects. The FBC approach has received much exposure by the television, newspaper, and magazine media since its inception. The paradigm is also a subject of numerous classroom discussions in the MIT SDM program.

The motivation for asking this question was to gain insight into what project managers actually perceive the highest risk aspects of FBC to be. The results may be useful to NASA as
they embark upon furthering the education of the project management approach to their workforce. The project managers were specifically asked to rank the requirements of optimal performance, minimum schedule, minimum cost, revolutionary technology infusion, and mission complexity in the order which they felt the requirement imposes a risk of project failure. The reader may refer to question B4 of the survey in Appendix B. Table 4.3 shows the final rankings which result from the study. The results were calculated by a method which applied a weighting scheme to determine the final rankings. The total number of votes each requirement received for a given rank position was multiplied by its corresponding weight. First place ranks were assigned a weight of 5 points, 2nd place ranks were assigned a weight of 4 points, etc., down to the last place rank assigned a weight of 1 point. A consolidated value for each requirement was then obtained by summing these weighted scores for ranks 1 thru 5. The consolidated values for each FBC factor were then compared to determine the order from highest to lowest risk driver. This method for determining a preference order is popular for situations where respondents have to prioritize choices, and was derived from lessons in Negotiation Analysis by Raiffa [18]. Figure 4.2 illustrates the comparative scores among the 5 FBC factors studied.

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Overall Rank Assigned</th>
<th>FBC Parameter</th>
<th>1st Place Votes Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest Risk</td>
<td>1</td>
<td>Revolutionary Technology Infusion</td>
<td>34 %</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Minimum Cost</td>
<td>24 %</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Minimum Schedule</td>
<td>16 %</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Mission Complexity</td>
<td>18 %</td>
</tr>
<tr>
<td>Lowest Risk</td>
<td>5</td>
<td>Optimum Performance</td>
<td>8 %</td>
</tr>
</tbody>
</table>

Table 4.3 Order of FBC Parameters for Driving Project Risk

Figure 4.2 Comparative Results of FBC Factors as Risk Drivers

It was interesting to observe that revolutionary technology infusion received the top rating as highest risk driver. This was also confirmed by comparing only the total number of 1st place votes for each FBC factor. For 34% of the project manager population, revolutionary technology infusion received 1st place votes. In contrast, optimum performance clearly secured the last place position by both tabulation approaches. Mission complexity was clearly deemed more of a risk.
driver than optimum performance, and slightly edged out minimum schedule by 1\(^{st}\) place votes only. However, minimum schedule received a greater number of 2\(^{nd}\) place votes than complexity to place it higher overall in the rankings. Although Figure 4.2 shows that cost and schedule are practically even as the 2\(^{nd}\) strongest risk driver, cost received 24\% 1\(^{st}\) place votes while schedule received only 16\% 1\(^{st}\) place votes. Cost was therefore considered to edge out schedule as the higher risk driver.

So what does this information tell us? Project managers recognize the challenge of incorporating revolutionary technologies in their project development efforts. Even though cost and schedule always seem to be an issue, in the minds of experienced project managers enabling technology infusion really puts the squeeze on the project's potential of success. More than half of the population surveyed (58.7\%) implemented 2-5 enabling technologies in their projects. Although the data does not clarify whether the concern is more focused on the infusion process itself or on the actual technology development, it is reasonable to suggest that the dependency upon enabling technology for a project is the most difficult of the FBC factors for which to control the project's outcome. The Project Management Institute [6] supports this view by stating that, with all other aspects remaining equal, systems which involve only proven technologies will involve less risk than systems requiring unproven technologies to make the mission feasible. The data results showed mission complexity to be a recognizable influence despite its 4\(^{th}\) place ranking. One can speculate that the respondents who rated complexity as a high risk driver may indeed have considered its interrelationship with product technology. If so, this would further substantiate the impact of new technology upon the success of a complex systems project.

Pate-Cornell and Dillon [17] claim that FBC constraints force projects to focus on schedule and budget, or else face cancellation. Project management under this condition apparently does not allow for revolutionary technology development and infusion to receive the attention it requires. Management needs to ensure up front that the resources fit the scope, with adequate reserves available to address the uncertainties associated with the revolutionary technology developments. The FBC formula must contain enough flexibility to support radically new technology developments, as well as successful mitigation strategies when these high risk technologies fail to meet the delivery date. The NIAT report discusses the need for an ongoing technology development pipeline, in order to reduce the risks associated with infusing new technologies into a given mission. Until such an infrastructure is operating successfully, the education of FBC to the project managers of NASA needs to highlight revolutionary technology infusion as a critical risk, and some strategies for mitigation which make sense in concert with the other FBC factors.

**Product Development Processes**

Project managers were queried to determine their attitude toward several different product development approaches. The reader may refer to question R7 of the survey in Appendix B. Of the four specific scenarios supplied, respondents were asked to rank them in the order which they felt how successful the given approach would be. The four processes with their corresponding results by project type are highlighted in Table 4.4.
Table 4.4 Rating Different Product Development Processes

<table>
<thead>
<tr>
<th>Option</th>
<th>Process Description</th>
<th>Most Successful Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Civil</td>
</tr>
<tr>
<td>A</td>
<td>Take the time to design and build it right the first time; catching problems in test phase should not be the baseline.</td>
<td>61.3%</td>
</tr>
<tr>
<td>B</td>
<td>Build a little and test a little, discovering and fixing problems as you go.</td>
<td>32.3%</td>
</tr>
<tr>
<td>C</td>
<td>Design, build, and test quickly; plan for making fixes/upgrades in the field after receiving user feedback.</td>
<td>3.2%</td>
</tr>
<tr>
<td>D</td>
<td>Design and build quickly, then test exhaustively to make sure all of the bugs are eliminated before delivery.</td>
<td>3.2%</td>
</tr>
</tbody>
</table>

Over 55% of the aggregate respondents chose option A as the most successful approach. This was also the most popular approach independent of sector. By comparison, option B received 31% of the aggregate most successful votes. Note that for the commercial sector, this approach was equal to option A. Although option C was ranked overall in third place, surprisingly 8.2% of the collective respondents ranked it as the top choice, and over 75% of the respondents felt it was the least successful product development approach. The military sector rated it equal to option B. Hypothesizing, this approach may be desirable when the need arises to deliver smart weapons quickly to the field, along with the ability to make adjustments to unique battlefield conditions. This approach is also common in the software industry, for releasing a product to the marketplace to beat their competition, while counting on user feedback to achieve the final level of quality. There are examples of spacecraft launched without the completion of final calibrations by software control algorithms, whereby uploads during the cruise phase toward its destination are planned to finish these tasks. The statistics suggest that option C is more likely to be an approach that is arrived at by problems that arise during the product development lifecycle, rather than one which is chosen as the preferred approach at project initiation. Option D was the least preferred process by the aggregate group, and was rated equal to option C in both the civil and commercial sectors.

Product Development Challenges

Project managers were instructed to rate three issues in the order which they challenged the product development process of their project. The reader may refer to question B12 of the survey in Appendix B. The issues and their corresponding results by project type are shown in Table 4.5. The challenges are provided in the table in order of the most challenging issue to the least challenging issue, as rated by the aggregate group. Looking more closely by project sector, the civil and commercial respondents chose issue A as the most challenging, while the military respondents chose issue B as the most challenging. The military and commercial sectors found issue C to be the least challenging, while the civil sector surprisingly found issue B the least challenging.
The military sector found responding to changes in project dynamics more challenging than external influences. This may suggest that with a formal chain of command, external influences are less of an issue than instability due to budgets, technical requirements, or staffing. The civil sector found making structural changes more of a challenge than changes in project dynamics. This is contradictory to the fact that resource instability was cited among the strongest negative impacts to a project.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Challenge</th>
<th>Frequency Found Most Challenging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Civil</td>
</tr>
<tr>
<td>A</td>
<td>Responding to external events and/or influences</td>
<td>62.5%</td>
</tr>
<tr>
<td>B</td>
<td>Absorbing changes in project dynamics (e.g. growth, stability, staffing)</td>
<td>15.6%</td>
</tr>
<tr>
<td>C</td>
<td>Making system structural changes/tradeoffs</td>
<td>21.9%</td>
</tr>
</tbody>
</table>

Table 4.5 Rating Different Product Development Challenges

Let’s make a comparison to System Dynamics research performed at MIT for these three issues. Figure 4.3 illustrates the project manager’s ability to influence each issue, from the system dynamics viewpoint [15]. As the figure points out, generally a project manager has a low ability to change external factors. There is a medium level of influence for patterns of behavior, i.e. changes to the dynamics of the project such as staffing levels and increases in requirements. The project manager generally has a high ability to influence changes in system structure, such as technical modifications to the product architecture, a product specification, or product function. The aggregate project group responded synchronously with the system dynamics model, suggesting that in a general sense, the projects experienced similar levels of challenges.

Figure 4.3 Project Manager Influence Over Key Factors
Shortening Project Completion Time

Project managers were asked to choose from three options which condition they felt had the largest impact on shortening the completion time for a project. The reader may refer to question S3 of the survey in Appendix B. The options and their corresponding results by project type are provided in Table 4.6.

<table>
<thead>
<tr>
<th>Option</th>
<th>Method</th>
<th>Frequency of Largest Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A reduction in the time to discover additional tasks required (due to work errors and/or incomplete requirements)</td>
<td>Civil: 40.6 %</td>
</tr>
<tr>
<td>2</td>
<td>An increase in worker quality (i.e. accuracy / error-free work)</td>
<td>Civil: 43.8 %</td>
</tr>
<tr>
<td>3</td>
<td>An increase in worker productivity</td>
<td>Civil: 15.6 %</td>
</tr>
</tbody>
</table>

Table 4.6 Rating Different Methods for Shortening Project Completion Time

The methods for shortening project completion time are provided in the table in order of largest impact to least impact, as rated by the aggregate group. Looking more closely by project sector, the civil projects chose option 2 as the largest impact, the military projects chose option 1, and commercial projects chose options 1 and 2 equally. The military sector found option 3 to not ever be the largest impact. By the civil sector selecting worker quality as the largest impact, it suggests that they may well understand the value of highly qualified, experienced personnel for producing error free work under tight time frames. The military sector felt that a reduction in time to discover additional tasks was the predominant factor for shortening the schedule, as opposed to increasing worker quality or productivity.

From a collective point of view, the data proposes that project managers mainly feel that if they can discover problems sooner, they can make the largest impact on minimizing the schedule. However, reducing the time to discover additional tasks required can have the smallest impact on improving project completion time. Further, even with discovering a problem quickly, it still requires making the correction, which adds time since you have more work to do. In contrast, increasing worker productivity was chosen only by a small minority of the population. Although increases to project productivity by training, overtime, or by additional staff help to reduce completion time, not as big an impact is made on schedule time reduction as with increases to worker quality. Also, since 84% of the respondents claim that their team members always or frequently face schedule pressure, the likelihood for an increase to worker productivity is quite small.

Related system dynamics simulations were conducted in October 2000 at MIT to generally observe how changes to worker quality, worker productivity, and delay to rework discovery time affect project completion time [15]. Models were validated with real projects from industry. Worker level of experience (quality), productivity (amount of tasks/person/month), and time to discover project errors (in months) were varied equally relative to their baselines, with changes to completion time recorded. Variations in worker quality were found to have the largest impact for reducing project completion time. The lower the quality of work performed, the more
revisions and/or iterations are required. Although for some models the reduction in the delay to discover rework had a lesser impact than productivity increases, while for other models the reverse was true, either was always a lesser impact to worker quality increases. The message here is that project management would benefit most by hiring the best people for the project, since the quality of the workers has the largest positive impact to minimizing the schedule.

**Insufficient Funding Early in a Project Lifecycle**

Project managers were asked their view on how much of an impact would receiving an insufficient portion of funding during the first 25% of a project’s lifecycle affect its success. The reader may refer to question C3 of the survey in Appendix B. Over 82% of the replies rated this situation as either a catastrophic or a significant impact. Just 17.5% claimed that it was manageable, while no one felt it would have little or no impact at all. Thus, project managers consider the delivery of fiscal resources on schedule with the proposed budget plans for the first quarter of the project duration, to be essential for preventing considerable impacts to success.

**Summary of Key Findings**

The project manager is viewed as the primary person responsible for risk management. The NIAT report concurs by stating that primary responsibility for effective risk management rests squarely on the shoulders of the project manager. However, more than just the project manager should be accountable for project risks. Ideally, risk management is the responsibility of everyone in the organization. The NASA Systems Engineering Handbook instructs that proper risk management requires a team effort. The NIAT Report specifically states that project team members must fully understand their role in the identification and control of risk. Conrow states that the effectiveness of a project’s risk management process is highly correlated with the attitude of the project manager and other key project personnel toward it. Effective risk management includes having an honest, unbiased attitude, the desire to learn and participate, the encouragement of the free flow of information between project team members and all levels of management, and active involvement in guiding risk management implementation and operation.

According to senior manager data, risk management practices should be emphasized no later than the design phase of a project. If at all possible, they should be emphasized as early as the project onset, and continue with steady discipline throughout the entire lifecycle. Senior managers find it very valuable to prioritize their organization’s projects according to schedule, performance, cost, scope, and innovation. This prioritization scheme makes it easier for senior management to identify the key risk drivers for each project, and allocate resources to effectively support them.

Revolutionary technology infusion is deemed the highest risk driver to a FBC project. Project managers recognize the challenge of incorporating revolutionary technologies into the product development process. This suggests that an organizational focus on technology development and infusion be applied, instead of the traditional preoccupations with cost and schedule. Although cost and schedule are obvious concerns for an FBC project, enabling technology development and infusion introduces the greatest level of uncertainty for controlling the project’s outcome. In educating FBC project management, NASA needs to emphasize this critical aspect, and mentor mitigation strategies which will work in unison with the other FBC factors.
The project manager considers the most successful product development approach to be to take the time to design and build the system right the first time. This suggests that an unrealistic schedule constraint should be avoided. However, the NIAT report encourages the need to find new ways of accelerating the introduction of new technologies into missions with shorter lifecycles. Based on the project manager's view of successful development practices, coupled with revolutionary technology infusion identified as the highest FBC risk driver, NASA may need to reconsider this push for accelerated technology infusion. It is likely to exacerbate a problem that is already there but not being appropriately addressed.

Since worker quality (experience) has the most pronounced effect on schedule time reduction, project managers must be more focused on developing quality teams and less on trying to discover mistakes faster. The NIAT report recommends the engagement of institutional managers and independent experts to increase the speed of detecting and correcting problems. The more effective approach is to enable the project teams with highly talented people, who will make less errors in the first place.

Project managers feel that responding to external influences is among the most challenging project management issues. This is also identified in the project manager responses for the strongest negative influences to a project. Thus, senior management must take responsibility for filtering out unnecessary external influences to the projects. The military projects did not cite external influences as the most challenging, suggesting that their management hierarchy may be effective at filtering external influences. The more time a project manager has to focus on the system development, the more likely it will be developed right the first time. The NIAT report does not mention external influences as a risk driver to projects. This is one key area that needs to be added to the NIAT list of actions.

Project managers believe that receiving an insufficient amount of project funding during the early part of the lifecycle will largely impact the project's outcome. Adequate financial resources up front play a big factor in the project meeting its original targets. Reinertsen [20] states that technical problems arise when there are inadequate resources to accomplish the system development tasks. Sometimes this occurs from incorrect estimations of the work required to complete the system. These incorrect estimations can be caused by poorly defined tasks, from too much optimism, or from adjustments to the resources by organizational managers. When correct estimates were generated, technical problems may still arise due to inadequately supporting these estimates.
Chapter 5
Project Preparation

The initial steps taken for getting a project off the ground has major implications downstream to the project’s outcome. This chapter investigates project preparation by focusing on two specific aspects: initial resources allocation, and team knowledge readiness. The topic of initial resources allocation explores the responses by project managers for what percentages of personnel and total budget their projects began with, how much of a schedule buffer was allocated, the timing that the highest risk technologies started their funding, and the influence of other projects needs on the selection of a project’s enabling technologies. The topic of team knowledge readiness is concerned with the perceptions of workforce training levels, development team understanding of the project’s link to the organization’s strategic plan, understanding of the project objectives and technologies selected for use, the application of prior projects and prior lessons learned, and the perception of team confidence.

Part I: Initial Resources Allocation

Percentage of Total Budget Requested

Project managers were asked to specify the percentage of financial resources requested that they actually initiated the project with. The reader may refer to question C1 of the survey in Appendix B. Table 5.1 illustrates the results by project type.

<table>
<thead>
<tr>
<th>% Funding at Project Start</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Civil</td>
</tr>
<tr>
<td>80-100 %</td>
<td>39.4 %</td>
</tr>
<tr>
<td>60-79 %</td>
<td>9.1 %</td>
</tr>
<tr>
<td>40-59 %</td>
<td>12.1 %</td>
</tr>
<tr>
<td>20-39 %</td>
<td>9.1 %</td>
</tr>
<tr>
<td>0-19 %</td>
<td>30.3 %</td>
</tr>
</tbody>
</table>

Table 5.1 Percentage of Funding at Project Start

From a collective viewpoint, nearly 43% of the respondents replied that their project received 80-100% of their budget request. About 30% of the respondents received <40% of the requested funding, with 22% of this group actually receiving <20% of their budget request. The results indicate that projects either start off financially on the right or the wrong foot. Experience demonstrates that a project should begin with as much funding up front as possible. This facilitates getting lengthy procurements underway, and also provides some protection against future budget shortages at a higher level (if you need more funding later and it isn’t available, your project is out of luck).

Looking a bit closer by project sector, we see that the civil sector exhibits the same problem as the aggregate group, either funded well or very poorly from the start. The military sector has half of their projects starting out acceptably, with a decreasing frequency toward worse financial conditions. The commercial sector has just over 40% of their projects at the 80-100% level, with an even distribution over the remaining worse financial brackets.
Percentage of Personnel Requested

Project managers were asked to specify the percentage of staff requested that they initiated the project with. The reader may refer to question S1 of the survey in Appendix B. Table 5.2 provides the results by project type.

<table>
<thead>
<tr>
<th>% Personnel at Project Start</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil</td>
<td>Military</td>
</tr>
<tr>
<td>80-100%</td>
<td>43.8%</td>
</tr>
<tr>
<td>60-79%</td>
<td>18.8%</td>
</tr>
<tr>
<td>40-59%</td>
<td>18.8%</td>
</tr>
<tr>
<td>20-39%</td>
<td>12.5%</td>
</tr>
<tr>
<td>0-19%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

Table 5.2 Percentage of Personnel at Project Start

The aggregate project group had only 37% of the projects beginning with 80-100% of personnel requested. A total of about 39% of the projects received under 60% of their requested staff. Independent of sector, as the percentage of initial personnel supplied decreases, so does the number of projects at that level of allocation. The civil sector shows the largest percentage of projects beginning with 80-100% personnel.

Studies in system dynamics reveal dramatic schedule slippage due to not starting a project with its required number of personnel. For our project population, 59% of the projects did experience some form of schedule slip. Smith and Reinertsen confirm the need for fully staffing project teams early. They assert that organizations often fail to realize the critical importance of having team members present for early team activities. Trying to save a little money by not assigning people before they are felt most needed, results in much greater expenses downstream in the project lifecycle. Dramatic increases in project duration translate into considerable budget overruns, in the form of employee overtime, contract extensions, re-planning, etc. Another reason for fully staffing a project team early is to allow all of the members to benefit from teambuilding simultaneously. Adding personnel downstream makes it much harder, if not impossible, for a new member to integrate synergistically with the existing members.

Reinertsen [20] continues by articulating that inadequate staffing during the early stages of a project is often a chronic complaint of development teams. The key technical members needed to get the project off the ground are still fighting fires on their previous program. This problem can be avoided by creating downtime for key technical people between high priority projects. This short time buffer can absorb the variability that exists from the previous project. This time is also valuable for the employee to pause and reflect. If a new project can begin with all of its members fully engaged, a positive influence on team dynamics will result.

Schedule Buffer Allocation

The amount of schedule buffer allocated for the projects were evaluated. The reader may refer to question S4 of the survey in Appendix B. Figure 5.1 exhibits a chart of the schedule buffer sizes for the surveyed group. Surprisingly, no schedule buffer at all was used for 13.6% of the projects. The dominant schedule buffer percentage carried is 10% of the project duration, representing 28.8% of the projects sampled. The next most frequent response was a 20% buffer, representing 15.3% of the projects. It is interesting to note that 63% of the projects carried 10%
or less of a schedule buffer, 88% of the projects carried 20% or less of a schedule buffer, and no buffer exceeded 33%. The response mean was 11.63% for the project population.

![Schedule Buffer Size](image)

**Figure 5.1 Schedule Buffer Size**

**Funding Start for Highest Risk Technologies**

Project managers were polled to determine which stage of the project that its highest risk technologies began funding. The reader may refer to question T3 of the survey in Appendix B. Table 5.3 shows the results from the aggregate project group. Slightly over 26% of the projects began high risk technologies funding before project conception. A cumulative 67% of the projects initiated their technology funding during the planning phase or before. One third of the projects didn’t initiate funding until the design or development stages.

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before project conception</td>
<td>26.2 %</td>
</tr>
<tr>
<td>Preparation phase</td>
<td>18.0 %</td>
</tr>
<tr>
<td>Planning phase</td>
<td>23.0 %</td>
</tr>
<tr>
<td>Design phase</td>
<td>24.6 %</td>
</tr>
<tr>
<td>Development phase</td>
<td>8.2 %</td>
</tr>
</tbody>
</table>

**Table 5.3 High Risk Technologies Funding Initiation by Project Phase**

Smith and Reinertsen [23] recommend that the highest risk technologies need to be funded early. Technology development proceeds according to a much more uncertain pace than product development. If a project is on an ambitious schedule, with the added requirement of enabling technologies, the earlier the technology developments begin funding the better. Not only must this funding start early, but it also must remain stable and free of being compromised as a result of other projects in crisis. Highsmith [12] adds that the longer a project waits to begin funding high risk technology development, the longer they are unsure of the project’s outcome. If the project is critically dependent upon an enabling technology, finding out sooner that the new
technology may not work will save project resources as well as provide more time for alternative action.

**Influence of Other Projects on Technology Selection**

The extent for which the selection of a project’s new technologies was influenced by their additional benefit to either future projects or other presently ongoing projects was examined. The reader may refer to question T4 of the survey in Appendix B. Table 5.4 illustrates the percentage of projects which felt a noticeable influence (defined here as either some, a significant, or a predominant influence). Data is broken down by project type for a comparison across sectors. The results suggest that the interests of other projects add another degree of complexity to a project’s requirements, when a specific new technology is selected for satisfying the objectives to more than one project.

<table>
<thead>
<tr>
<th>Percent of Projects Noticeably Influenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civilian</td>
</tr>
<tr>
<td>59%</td>
</tr>
</tbody>
</table>

*Table 5.4 Percentage of Noticeable Influence on a Project for Technology Selection*

Pushing this matter a bit further, a strong correlation was discovered between the level of influence upon technology selection by other projects and the number of enabling technologies used. Table 5.5 shows that as the number of enabling technologies included in a project increases, the percentage of projects having a strong influence (defined here as either a significant or predominant influence) by other projects increases. The correlation also holds up for a noticeable level of influence.

<table>
<thead>
<tr>
<th>Number of Enabling Technologies</th>
<th>Percent of Projects Noticeably Influenced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>2 to 5</td>
<td>43%</td>
</tr>
<tr>
<td>6 or more</td>
<td>63%</td>
</tr>
</tbody>
</table>

*Table 5.5 Correlation Between a Strong Influence on Technology Selection and Number of Enabling Technologies Used*

This finding suggests that as a project plans to infuse more enabling technologies, there is an increasing probability that other projects will exert an influence on the selection process. This makes sense, since the more technologies being developed, the greater the likelihood that another project will also find them attractive to use. The problem is that it doesn’t take a large number of technologies for a project to become overwhelmed with external technology requirements. Thus, the project can get sidetracked from its original mission by attempting to satisfy, at least in part, other project requirements. The data in Table 5.5 suggests that project management must successfully mitigate these influences from other projects when the number of enabling technologies reaches 2 or more.
Part II: Team Knowledge Readiness

Percentage of Workforce Sufficiently Trained

Senior manager perceptions for the percentage of the technical workforce which presently holds a sufficient level of training for the development of revolutionary complex systems was sought. The reader may refer to question R5 of the survey in Appendix A. Two thirds of the respondents rated <60% of their workforce with sufficient training. No respondents felt that 80% or more of their workforce was amply trained. These results suggest that technical training should be a continuous, ongoing activity for the employees to make up for this deficiency, as well as prepare for the future. Since project managers claim that over 84% of team members face frequent to continuous schedule pressure, technical personnel may suffer from an inability to stay current with learning due to the absence of any time in their schedule for training activities.

Understanding of the Organization’s Strategic Plan

Both senior managers and project managers were asked the question of how well they believed that project development teams understood how their project specifically relates to and/or ties into the long-term strategic plan of the organization. The reader may refer to question R13 of the survey in Appendix A, and question B1 of the survey in Appendix B. Table 5.6 illustrates the results from the two survey populations.

<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>SM Frequency</th>
<th>PM Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorough</td>
<td>9.5%</td>
<td>14.5%</td>
</tr>
<tr>
<td>Good</td>
<td>47.6%</td>
<td>43.5%</td>
</tr>
<tr>
<td>Adequate</td>
<td>28.6%</td>
<td>25.8%</td>
</tr>
<tr>
<td>Poor</td>
<td>14.3%</td>
<td>16.2%</td>
</tr>
</tbody>
</table>

Table 5.6 Manager Perception of Team Member’s Understanding of Project Relationship to the Strategic Plan

A large majority of senior managers (86%) felt that their project teams had an adequate or better understanding of the relationship between the project and the strategic plan. Notice that only 9.5% of the senior managers said their teams possessed a thorough understanding. A senior manager rating of poor understanding (14.3%) outweighed a rating of thorough understanding (9.5%) by over 50%. As a whole, the project managers rated their teams similarly. Over two thirds of project managers (84%) perceived their team members to maintain an adequate or better understanding. A higher frequency of project managers than senior managers felt that team members had a thorough understanding. Once again, a poor understanding (16%) did outweigh a thorough understanding (14.5%). The fact that over 50% of the senior managers and project managers felt the understanding of the project team members was good or thorough, suggests there may be some overconfidence of the team’s strategic plan knowledge by management. A correlation between the level of understanding the project relationship to the strategic plan and team confidence is discussed in the section on team confidence.

Understanding of Project Objectives

Project managers were polled to determine how well they perceived their team members understanding to be of their project’s mission statement, primary objectives (live or die goals),
and secondary (desirable but not essential) objectives during product development. The reader may refer to question B2 of the survey in Appendix B. Table 5.7 provides the results. A correlation between the level of understanding of project objectives and team confidence is discussed in the section on team confidence.

<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorough</td>
<td>23.8%</td>
</tr>
<tr>
<td>Good</td>
<td>44.5%</td>
</tr>
<tr>
<td>Adequate</td>
<td>19.0%</td>
</tr>
<tr>
<td>Poor</td>
<td>12.7%</td>
</tr>
</tbody>
</table>

Table 5.7 Manager Perception of Team Member's Understanding of Project Objectives

Over two thirds (68%) of the respondents felt their team had a thorough or good understanding of the mission objectives. No project managers felt that team members lacked any understanding at all, but 12.7% did rate their team with a poor understanding. The complete understanding of a project's mission statement, and primary and secondary objectives are critical to meeting the requirements and producing a successful product architecture. Crawley [4] states that the understanding of project goals, and the decomposition of the project mission statement into its lower level objectives, is a key to driving ambiguity from a complex system. The elimination of system ambiguity is essential for delivering product functions which properly capture the project's goals. Further, removing ambiguity aids in the reduction of system performance uncertainty. Thus, when project team members have a thorough understanding of the project goals and their interrelationships, the development of a high quality, robust design is possible. High quality, robust designs are effective at mitigating unknown risks during the operation phase.

Understanding the Technologies Used

How well project team members truly understood the technologies selected for use was inquired from the project manager population. The reader may refer to question T2 of the survey in Appendix B. Table 5.8 shows the results.

<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely good</td>
<td>12.7%</td>
</tr>
<tr>
<td>Very good</td>
<td>46.0%</td>
</tr>
<tr>
<td>Average</td>
<td>36.5%</td>
</tr>
<tr>
<td>Poor</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

Table 5.8 Manager Perception of Team Member's Understanding of Technologies Used

Over half of the project group (59%) was believed to contain a very good or better understanding. Those considered to have an average or poor understanding of the technologies amounted to 41% of the group. No respondent felt the level of understanding was completely absent. An intricate understanding of the technologies used by the technical team members is critical to the successful development of a complex system, and is likely to drive the
performance, cost, and schedule factors of the project. A correlation between the level of understanding of technologies used and team confidence is discussed in the section on team confidence.

The Use of Prior Projects

Project managers were asked to select the extent for which prior projects were used to determine the project’s scope, schedule, budget, and performance. The reader may refer to question R4 of the survey in Appendix B. Table 5.9 highlights the results.

<table>
<thead>
<tr>
<th>Amount Prior Projects Were Used</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominantly</td>
<td>11.3%</td>
</tr>
<tr>
<td>Significantly</td>
<td>40.3%</td>
</tr>
<tr>
<td>Somewhat</td>
<td>35.5%</td>
</tr>
<tr>
<td>Barely</td>
<td>8.1%</td>
</tr>
<tr>
<td>Not at all</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

Table 5.9 Use of Prior Projects for Determining New Project Requirements

Over 50% of the projects feel they use prior projects significantly or predominately for developing the new project’s requirements. The use of prior projects barely or not at all amounted to just 13%. Prior projects serve as real indicators whether the scope, performance requirements, cost projections, and schedule allocation were appropriate for the undertaking. When properly applied, this information can realistically position a project during its preparation phase and set the stage for a high probability of success. Historical project information contains documented data about what actually happened during previous project developments and operations, and is an ideal way to develop requirements and mitigate potential risks. Rechtin states that it is reasonable to believe that prior project developers knew what they were doing in the context of their time and circumstances. Therefore, their systems deserve the study time. Their successes and failures are living demonstrations of what works and what doesn’t work.

The Use of Prior Lessons Learned

Project managers were surveyed to determine the level of review and understanding of lessons learned from relevant projects the team members possessed before starting work on the project. The reader may refer to question R1 of the survey in Appendix B. Lessons learned can be viewed as a form of academic preparation for a project. Table 5.10 illustrates the results.

<table>
<thead>
<tr>
<th>Review of Prior Lessons Learned</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorough</td>
<td>7.9%</td>
</tr>
<tr>
<td>Good</td>
<td>33.3%</td>
</tr>
<tr>
<td>Average</td>
<td>42.9%</td>
</tr>
<tr>
<td>Poor</td>
<td>14.3%</td>
</tr>
<tr>
<td>None at all</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Table 5.10 Level of Review and Understanding of Prior Lessons Learned

Over 40% of the managers claimed their team members held a good to thorough level of review and understanding of prior lessons learned. The a priori expectation was a substantial response rate in the poor to none categories. On the contrary, only a total of 16% rated their team
members with either a level of review and understanding that was poor or non-existent. The considerable importance of prior lessons learned has been recognized by NASA in recent years. The agency has responded by developing and maintaining a Lessons Learned website for all to reference.

Interesting correlations significant to the 0.01 level were uncovered between the use of prior lessons learned and the level of operations personnel and stakeholders for the development of project specifications. As the project team’s review and understanding of prior lessons learned from relevant projects improve, the significant use of operations personnel and stakeholders for developing specifications increase. Tables 5.11 conveys this relationship. We see that as the review and understanding of prior lessons learned ranges from poor to thorough, the involvement in developing specifications by operations personnel and stakeholders increase from 33% or less to up to 100% of the time.

<table>
<thead>
<tr>
<th>Employee Type</th>
<th>Thorough</th>
<th>Good</th>
<th>Average</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operations Personnel</td>
<td>80%</td>
<td>76%</td>
<td>56%</td>
<td>22%</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>100%</td>
<td>75%</td>
<td>70%</td>
<td>33%</td>
</tr>
</tbody>
</table>

**Table 5.11 Degree of Specifications Involvement vs. Prior Lessons Learned**

This relationship suggests that project teams significantly engage operations personnel and stakeholders in the early stages of product development more often as their comprehension of relevant prior lessons learned increases. This knowledge must be conveying the importance of these types of employees in the specifications process for reducing risks.

The level of review and understanding for prior lessons learned has a similar influence on team confidence. A Pearson correlation significant to the 0.01 level was revealed between these two project facets. The correlation data shows that as the level of review and understanding of prior lessons learned improves, so does the level of team confidence.

**Level of Team Confidence**

The project team’s level of confidence for meeting the cost, schedule, and performance goals was rated by the project managers surveyed. The reader may refer to question R6 of the survey in Appendix B. Less than 5% of the aggregate project responses cited extremely confident teams. The significant majority of teams (83%) fell in the range of somewhat to very confident. Teams barely confident or not at all confident consisted of 13% of the entire group. Figure 5.2 represents these distributions in graphical form.

Team confidence is an attribute that is highly desired, but can also have a detrimental effect when present. There are a number of research findings which point out the tendency for a project team to overestimate their ability to successfully tackle the challenges of the complex system development. A specific case of this was found by the NASA Mars Climate Orbiter Failure Report. The report pointed out that team overconfidence was a significant influence for overlooking the navigational errors that existed in the spacecraft’s control software.
Level of team confidence was found to be well correlated with a number of other aspects of project preparation. The percentage of incidences of high team confidence increases as the understanding of the enabling technologies used in the project improves. Figure 5.3 illustrates this effect. We see that the percentage of very confident to extremely confident teams increases from 0% to 75% as the understanding of the project technologies improves from poor to extremely well.

![Figure 5.2 Perceived Level of Project Team Confidence](image)

![Figure 5.3 Percentage of High Project Team Confidence as a Function of Understanding Technologies Used](image)

Level of team confidence was also found to be correlated with the team’s understanding of the project’s objectives and the project’s relationship to the organization’s strategic plan. As the understanding of project objectives and relationship to the strategic plan improves from poor to
thorough, the percent of highly confident project teams rise considerably. Figure 5.4 provides the data.

![Figure 5.4 Percentage of High Team Confidence as a Function of Understanding Project Objectives & Relation to Strategic Plan](image)

We see from Figure 5.4 that the average level of understanding for the relationship to the strategic plan actually possesses a lower percentage of high team confidence than for a poor understanding. The reason for this is due to the significance of the correlation. The Pearson correlation for relation to strategic plan vs. team confidence is slightly above the ** level (0.015). In comparison, the Pearson correlation is well below 0.01 for the understanding of project objectives vs. team confidence. Thus we see in this data series a clear increase in project frequency with improvement in the understanding of project objectives.

Level of team confidence is also Pearson correlated with team leader authority. As the authority of the team leader increases from lightweight to full authority, the team confidence level increases from low to high. Figure 5.5 illustrates a scatter plot of this relationship, with a regression line to highlight the strength of authority on team confidence. We see from the figure that the level of confidence does consistently increase as more authority is assumed by the team leader (project manager). However, less than one classification increase (e.g. somewhat → very confident) in team confidence is achieved for an increase in authority across the range of possible options (lightweight → full authority). This result suggests that increasing the level of team leader authority provides a modest gain in team confidence.

**Summary of Key Findings**

Projects seem to either start off with ample funding or severely restrained. The vast majority of the projects start with less than required fiscal resources. Most of the projects also do not begin with the required staffing level. Lack of a full staff at project commencement is well known to significantly contribute to schedule slippage, and in some cases can also lead to performance failure. Inadequate staffing of navigation operations team members was one of the contributing causes for the Mars Climate Orbiter (MCO) mission failure.

The typical schedule buffer size is 10% of the baseline project duration. The overall statistics suggest that the schedule buffer is not sufficient for the average project's duration, number of
enabling technologies, and resource allocation phasing. One-third of the projects did not fund their highest risk technologies until the design or development phases, while only one quarter began funding at project inception. The NIAT Report clearly emphasizes the need for stable and adequate technology development funding. The long term NASA solution is the development of a continuous technology pipeline external to mission development. However, until a successful technology pipeline is in place, high risk mission technologies must be funded early. The selection of new technologies for a project is often influenced by the interests of other projects in the organization. As the number of enabling technologies for a project increases, the influence over those technologies exerted by other projects in the organization increases. This suggests that the interests of other projects add another degree of complexity to a project’s requirements.

![Plot of Team Confidence Level vs. Team Leader Authority](image)

**Figure 5.5 Plot of Team Confidence Level vs. Team Leader Authority**

Top managers consider significant portions of the workforce to not be sufficiently trained for revolutionary complex system developments. A recent ramification of this was the NASA MCO mission failure, where a lack of sufficient team training was considered a contributing cause. Therefore, training must be made a high priority, and be a ongoing activity which the employees engage in. Ample time must be made available in an employee’s schedule for the pursuit of training. The lack of sufficient training may also be due to the fact that complex systems design and management is still in its infancy. There are few academic training programs presently in the world that can deliver in-depth and practical knowledge in this area. This may be partly why senior executives feel that there is no substitute for work experience. However, improving management awareness for complex systems development within organizations is necessary.
Promoting an active national community for the subject for information sharing would also help. It would be a critical step toward ensuring that accumulated experience develops into gained knowledge that is successfully transferred to others.

Both senior managers and project managers feel their project development teams have an acceptable level of understanding of how their projects relate to the organization’s strategic plan. There is also similar confidence by the project manager in the team’s understanding of project objectives and the technologies used. There are strong correlations among the level of understanding for mission objectives, how the project relates to the organization’s strategic plan, and the technologies used. This suggests that the project teams which invest in understanding their project’s goals and objectives well, while also understanding the project’s strategic importance, also are diligent in learning the technologies they are infusing.

Project managers perceive considerable use of prior projects for determining a project’s scope, performance, schedule and budget parameters. There is also significant review and understanding of prior lessons learned by team members before the project begins. These perspectives seem to be somewhat of an overconfident estimate by the project managers surveyed. Diligent application of prior project data and lessons learned is a necessary, but often overlooked exercise by burdened project teams. The Mars Climate Orbiter (MCO) mission failure occurred in part due to the navigation team unfamiliar with the spacecraft. The MCO team was also cited for overconfidence by review boards. This suggests that the project team must make sufficient efforts to use the historical information available, despite their perception of how well they understand the aspects of the project.

A relationship was discovered between the use of relevant prior lessons learned and the level of operations personnel and stakeholders used for the development of project specifications. As the project’s review and understanding of relevant prior lessons learned increases, so does the level of involvement by operations personnel and stakeholders in the early stages of product development. The study of past lessons learned must be highlighting the importance for the presence of these disciplines early in the project lifecycle.

Level of team confidence was found to be well correlated with a number of other project preparation attributes. As the team’s understanding of the enabling technologies selected for use improves, so does their level of confidence. Similarly, as the team’s understanding of the project’s objectives and the relationship to the organization’s strategic plan improves, the level of confidence rises considerably. Team confidence was also well correlated with team leader authority. As the project manager assumes more direct authority over the team members, the level of team confidence increases.
Chapter 6

Project Team Structure

This chapter focuses on some of the structural aspects of team formation and dynamics. The responses of senior managers and project managers are discussed regarding the amount of authority the project manager exercises as team leader, the degree of team member collocation, the number of other projects for which a team member’s time is typically shared, the perceived impact due to staffing changes, and the views managers have toward interchanging engineers on teams to solve organizational challenges.

Team Leader Authority

Project managers were questioned on the degree to which they had authority over the members of their project team. The reader may refer to question B10 of the survey in Appendix B. Their choices ranged from minimal to maximal authority over the administrative and technical aspects of the team members. Results are found in Table 6.1 along with the data for team collocation. About one-fourth (25.4%) of the population were lightweight team leaders for their projects, i.e. a functional manager in another division of the organization has both administrative and technical authority over the team members. The most common situation for the group was a balanced matrix (31.7%), i.e. the team leader shares equal authority along with the team member’s functional manager for both the administrative and technical details. Heavyweight team leaders were the least common of the group, comprising 19% of the projects. A heavyweight team leader maintains full technical authority while the functional manager handles only the administrative aspects. Full team leader authority was executed 23.8% of the time, i.e. the team leader held both administrative and technical authority over the team members. In chapter 6, it was found that increasing the level of team leader authority provides a moderate improvement in team confidence.

Team Member Collocation

The degree to which the project team members were collocated with the project manager was investigated. The reader may refer to question B11 of the survey in Appendix B. The choices ranged from team members residing fully with their functional organizations to fully with the project’s organization. Table 6.1 provides the results along with the data for team leader authority. For 20.6% of the projects, team members all resided in their functional organizations. Some to most of the team being collocated to the project organization amounted to 73% of the set. Only 6.3% of the project teams were fully collocated to the project organization.

<table>
<thead>
<tr>
<th>Case</th>
<th>Team Leader Authority</th>
<th>Frequency</th>
<th>Amt. of Collocation</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lightweight</td>
<td>25.4 %</td>
<td>None</td>
<td>20.6 %</td>
</tr>
<tr>
<td>2</td>
<td>Balanced Matrix</td>
<td>31.7 %</td>
<td>Some</td>
<td>34.9 %</td>
</tr>
<tr>
<td>3</td>
<td>Heavyweight</td>
<td>19.1 %</td>
<td>Most</td>
<td>38.2 %</td>
</tr>
<tr>
<td>4</td>
<td>Full</td>
<td>23.8 %</td>
<td>All</td>
<td>6.3 %</td>
</tr>
</tbody>
</table>

Table 6.1 Team Leader Authority vs. Collocation
The amount of collocation corresponds well with team leader authority for cases 1 and 2. However, cases 3 and 4 show a discrepancy between the amount of collocation and level of team leader authority. For projects that assign heavyweight or full authority to the team leader, there may be work that needs to be done at multiple locations, due to the size of the project or number of partner organizations involved. Economics may also play a role, since collocation requires substantial moving costs, especially for short-term projects. There may also be facility constraints which prevent a team from moving to one location due to a lack of available space.

MIT Professor Tom Allen has discovered through an ongoing study over several decades an important aspect regarding team collaborative collocation [14]. Based on proximity, people are not likely to collaborate very often if they are more than 50 feet apart. Therefore, to obtain the benefit of working together in the same place, team members need to be housed considerably close together.

**Number of Other Projects a Team Member Works**

Project managers were asked to provide the typical number of other projects that team members concurrently worked on in addition to their project. The choices ranged from no other projects to 4 or more projects. The reader may refer to question S6 of the survey in Appendix B. Table 6.2 shows the results. The table groups the data by total project count for easy comparison to Figure 6.1 below.

<table>
<thead>
<tr>
<th>Number of Total Projects</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only 1 project</td>
<td>25.4 %</td>
</tr>
<tr>
<td>2 projects</td>
<td>36.5 %</td>
</tr>
<tr>
<td>3 or more projects</td>
<td>38.1 %</td>
</tr>
</tbody>
</table>

**Table 6.2 Total Number of Projects a Team Member Works Simultaneously**

The ability of a project to meet its performance, cost, and schedule goals declines dramatically as the key project team members increase the total number of other projects they work on simultaneously. As discussed by Stern [25], a dramatic decline in productivity occurs once an employee is simultaneously working on more than two teams. Creativity becomes hampered by the lack of time and energy level of overburdened engineers. This is a key finding from literature sources on cross-functional teams. Figure 6.1 highlights the decline in productivity vs. the number of projects an engineer juggles. Organizational experiences have also revealed that project success throughout the entire lifecycle is dependent upon the ability of the project manager to establish stable team support from the team members’ line managers. Smith and Reinertsen also claim that managers underestimate the difficulty of making a fragmented team work successfully.

The data supports the fact that for the majority of the projects (62%), the team members had what is considered an acceptable workload in terms of organizational project efforts. However, a large percentage of the project teams are either always or frequently under schedule pressure. A statistical correlation could not be found between the number of projects a team member works, and schedule pressure or schedule slippage. This leads to two possible conclusions. One conclusion is that schedule delays must be emanating from another source. The second
conclusion is that project manager perception of the number of projects their team members are working on may be underestimating the real situation.

![Figure 6.1 Effect of Team Member Workload vs. Project Productivity](image)

**Figure 6.1 Effect of Team Member Workload vs. Project Productivity**

**Staffing Changes**

Senior managers were polled to assess how much of an impact staffing changes performed in between phases of a project’s lifecycle has on the outcome of the project. The reader may refer to question R8 of the survey in Appendix A. Table 6.3 illustrates the findings.

<table>
<thead>
<tr>
<th>Staffing Change Impact</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tremendous</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Considerable</td>
<td>71.4 %</td>
</tr>
<tr>
<td>Some</td>
<td>19.0 %</td>
</tr>
<tr>
<td>Little</td>
<td>4.8 %</td>
</tr>
</tbody>
</table>

**Table 6.3 Manager Perception of Staffing Change Impacts**

Over three-fourths (76.2%) of the group evaluated this impact as considerable or tremendous. No respondent rated the change as no impact at all, and less than 5% rated it as little impact. Interestingly, this approach to solving an organization’s dynamic needs for personnel seem to happen quite frequently. This is the common “firefighting” management approach used to address the latest emergency of the week. This approach focuses on the near-term crisis while postponing the longer-term “big picture” of the organization. As there are always ramifications to everything we do, one has to question whether sacrificing tomorrow to survive today is really tolerable. An interview respondent claimed that in many cases, an organization cannot prevent such changes in staffing. The key is for the organization to prepare for such transitions, in order to minimize the impact to the organization. In some cases, staffing changes between phases can be advantageous due to the unique strengths of the individuals involved. For example, some engineers are stronger in project formulation than they are during implementation phase, and vice-versa.
Team Member Interchangeability

Both senior managers and project managers were queried for how strongly they believed in the theory that engineers are “interchangeable” on product development teams. This means, for example, that a key mechanical engineer on project X can be suddenly reassigned to project Y, while project X receives another mechanical engineer from the organization as a substitute, thus experiencing little or no impact to the project’s ongoing activities. The reader may refer to question R12 of the survey in Appendix A, and question B9 of the survey in Appendix B. Table 6.4 provides the data results.

Senior managers somewhat to fully disagree with this belief 80% of the time. Project managers somewhat to fully disagree with this belief 92% of the time. Not only did a larger majority of the project managers have this level of disbelief, but the strength of their response for full disagreement with the concept (52.4%) significantly outweighed that of the senior managers (30%). It is interesting to note that no senior manager or project manager felt in full agreement with the concept. These results tell us that senior managers consider this belief more plausible than the project managers do. This makes sense since the senior manager is preoccupied with meeting the challenges for all of the organization’s projects from a holistic sense, while the project managers are directly responsible for meeting the needs of their project. This data supports the finding in chapter 8 that senior managers significantly emphasize strong leadership by the project manager as the greatest positive impact to a project, while project managers significantly emphasize the quality of their team. Therefore, the project managers appear to be more concerned with maintaining team stability than senior managers are.

<table>
<thead>
<tr>
<th>View on Interchangeability</th>
<th>SM Frequency</th>
<th>PM Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somewhat disagree</td>
<td>50.0 %</td>
<td>39.7 %</td>
</tr>
<tr>
<td>Fully disagree</td>
<td>30.0 %</td>
<td>52.4 %</td>
</tr>
</tbody>
</table>

Table 6.4 Manager Views on Team Member Interchangeability

This type of reassignment can occur for many reasons, but two common examples are that project Y is a project now in operational phase which suddenly experiences an emergency, or project Y is a new initiative with a priority such that the organization feels it must leverage its best resources to get the project off the ground running with a good start. Matrix organizations tend to solve their short term personnel requirements by moving engineers around frequently. Sometimes it is easy for a manager to believe that engineers are interchangeable since they all receive similar training, and in some sense provide the organization a similar service. This is connected to the theory that scientists were meant to be specialists while engineers were meant to be generalists, i.e. a “jack of all trades” problem solver.

An interview respondent discussed the fact that an organization must be adequately prepared for the interchanging of team personnel. The organizational system can be successful at doing this if it understands the skill needs of each of the projects. As a reference, successful changes of the project manager midcourse in a project have been handled successfully before. As mentioned in the previous section, in some cases the interchanging of engineers can be advantageous due to the unique strengths of the individuals.
Summary of Key Findings

Although the project set included a mixture of heavyweight and full authority team leadership, lightweight to medium team leader authority was favored. This could be related to the experience of the project managers surveyed. A mean of 3 projects represented the experience of the aggregate project managers. If organizations assign an increasing level of authority as a project manager gains experience, then the levels of team leader authority appear justified. Collocation was exercised for 80% of the projects, varying in degree from some to all of the team members. There is a strong correlation between the number of projects a technical member works on simultaneously and the amount of collocation used in a project. As you would expect, the more team members are collocated to a project, the less likely they are to work on other projects concurrently. Thus, one organizational strategy to limit employee overburdening is to create more collocated project structures. However, there is a problem with this strategy. Virtual teaming is quickly becoming the reality of tomorrow. More and more team members will perform their work with less face-to-face interaction as time goes on. This leads to the need for finding another method for controlling the over-subscription of technical employee time.

For this project data set, the number of concurrent projects that team members multiplex does not appear to be a significant factor for delaying the project schedule. Although senior managers strongly feel that staffing changes in between phases of a project will significantly impact the project, in many cases they believe that it cannot be avoided. The same is true for team member interchangeability. The data did reveal that project managers are more concerned with avoiding interchangeability than senior managers are. Since a main concern of the project manager is to maintain a stable team, this makes sense.

The criticality for maintaining staffing stability throughout the project lifecycle was demonstrated by the NASA Mars Climate Orbiter mishap. The inadequate transition of the systems engineering process from development phase to operations phase was deemed a contributing cause for the failure. One interview respondent proposes the solution for complex organizations such as NASA to be to prepare the workforce skill mix such that these changes can be absorbed with minimal or no impacts. Reinertsen [20] claims that the problem of staffing is truly one of management priority. When a new project truly has the priority it needs in the organization, there is usually little problems related to staffing. When management instead focuses on satisfying customer requests or maintaining too many projects with equal priority, resources will constantly be stolen away from a project, causing a rise in its probability of a negative outcome.
Chapter 7

Project Team Interactions

This chapter attempts to reveal some of the aspects involving the internal and external interactions of the project team. By reviewing the responses from the sampled projects, we observe the frequency of team meetings, the team member visibility to the project's master schedule, and the involvement of customers/stakeholders, operations personnel, and scientists for developing product specifications.

Frequency of Team Meetings

Project managers were asked to provide their best estimate for the frequency of project team meetings involving all of its members. These meetings were to include off-site team members, whether physically present in the meeting room, or tied in via video or tele-conferencing. The reader may refer to question B3 of the survey in Appendix B. Table 7.1 illustrates the findings.

<table>
<thead>
<tr>
<th>Meeting Frequency</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twice per week</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Once per week</td>
<td>61.9 %</td>
</tr>
<tr>
<td>Once every 2 weeks</td>
<td>15.9 %</td>
</tr>
<tr>
<td>Once every 3 weeks</td>
<td>1.6 %</td>
</tr>
<tr>
<td>Once per month</td>
<td>9.5 %</td>
</tr>
<tr>
<td>Less than once per month</td>
<td>6.3 %</td>
</tr>
</tbody>
</table>

Table 7.1 Team Meeting Frequency

Almost two-thirds of the respondents (62%) held meetings once per week. Collective behavior of having meetings at least once every two weeks, or more often, amounted to 82.6% of the projects. Of this segment, 4.75% actually held meetings an average of twice per week. These results point out good practices for encouraging and maintaining communication with all members of the project team. Statistically speaking, the frequency of team meetings was not found to be a factor in influencing schedule slips, budget overruns, or performance degradation.

Visibility of Master Schedule

Project managers were polled to determine the methods by which they presented the latest versions of the project's master schedule to the team members. The reader may refer to question S2 of the survey in Appendix B. Table 7.2 provides the methods and their corresponding response rates.

<table>
<thead>
<tr>
<th>Schedule Visibility Method</th>
<th>Frequency Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handed out at team meetings</td>
<td>46.0%</td>
</tr>
<tr>
<td>Stored electronically on a project website</td>
<td>30.2%</td>
</tr>
<tr>
<td>Posted on a common wall</td>
<td>12.7%</td>
</tr>
<tr>
<td>Shown to team members upon their request</td>
<td>9.5%</td>
</tr>
<tr>
<td>Not distributed at all</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Table 7.2 Methods for Displaying the Master Schedule
The dominant approach was to hand out the schedule at team meetings. Posting to a common wall occurred only 13% of the time. The use of a project website as the primary means to display the latest schedule amounted to almost one-third of the projects. Believe it or not, one project did not distribute the master schedule at all. Six projects only showed it upon request.

The preferred approach is to post the schedule to a common wall [23]. By doing this, the schedule serves as a constant reminder to the team members each time they walk past it. One large schedule along the wall can facilitate the observation of relationships between deliveries of subsystems, the timing of reviews, etc. Handing out photocopies of the latest schedule at team meetings is a generally acceptable approach, except when a team member misses a meeting, or the team member accidentally works to a version which is no longer the latest. Since the project manager probably juggles schedule events frequently, it is critical for all team members to be working to the latest schedule synergistically. Storing the latest schedule on a project website has the distinct advantage of always being able to retrieve it from any location, including while on travel. However, a team member must make a conscious effort to check the website frequently. Hence, out of sight, out of mind!

There is a relationship between schedule visibility and schedule slippage in the project data set. The key finding is that when schedule visibility is restricted to being shown only upon request, or not shown at all, schedule slip occurred 100% of the time. This tells us that at least some effort must be made by the project manager to inform the team members of the master schedule and keep them focused on it.

Schedule visibility was cross-tabulated with amount of project team collocation to investigate the existence of any potential relationship in the data set. One can speculate that fully collocated teams might post the master schedule to a common wall a majority of the time. This was not discovered to be the case. On the contrary, there was a rather even distribution of projects posting the schedule to a common wall independent of the level of collocation. One might also speculate that schedule distribution by electronic website might be the more common choice when most or all of the team members are housed in their functional organizations. However, this was not found to be the case either. The distribution was found to be equally balanced for teams primarily collocated as those which were primarily functionally separate.

**Stakeholder, Operations Personnel, and Scientist Involvement**

Project managers were asked to provide the level of involvement by key customers/stakeholders, operations personnel, and scientists for the development of their complex system specifications. System specifications are intended here to mean the precise description of what the system has to do, by establishing the key technical parameters to bound the ranges of normal operation. The reader may refer to questions B5, B6, and B7 of the survey in Appendix B. Table 7.3 provides the results for the involvement of these employees by project type.

From an aggregate perspective, a whopping 69% of the projects used key customers/stakeholders considerably for developing system specifications. A considerable level is defined here as either a substantial or above average level of involvement. Inspecting by sector, the civil projects used key customers/stakeholders more than the military or commercial projects. This defies the expectation that the commercial sector would have mostly involved customers. Operations personnel were used an average of 60% for the projects, with the civil sector once
again having the highest percentage (64%) of the three sectors. Scientists were used an average of just under 50% of the time, with the civil sector using them more than the military or commercial arenas. Key customers/stakeholders were found to be used more than operations personnel or scientists by sector as well as by the aggregate group.

<table>
<thead>
<tr>
<th>Personnel Type</th>
<th>Civil</th>
<th>Military</th>
<th>Commercial</th>
<th>Aggregated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Customers/Stakeholders</td>
<td>75.0 %</td>
<td>62.5 %</td>
<td>64.3 %</td>
<td>69.3 %</td>
</tr>
<tr>
<td>Operations Personnel</td>
<td>63.6 %</td>
<td>56.3 %</td>
<td>57.2 %</td>
<td>60.4 %</td>
</tr>
<tr>
<td>Scientists</td>
<td>57.6 %</td>
<td>33.4 %</td>
<td>35.7 %</td>
<td>46.7 %</td>
</tr>
</tbody>
</table>

Table 7.3 Levels of Considerable Personnel Involvement for Developing System Specifications

Frequent interactions with key personnel external to the core team are absolutely essential for project success. Many organizations have trouble with involving operators into the early project phases. Some of this may be due to management oversight for holistic, end-to-end involvement. Some of this is due to the project not yet being at a stage that is exciting enough to stimulate the participation of these “hands-on” types. The lack of more scientists involvement cannot be readily explained. Operations personnel and scientists involvement was far lower in the civil and military sectors than it should be. The NIAT Report specifically indicates the early project involvement by scientists, and operations personnel in order to reinforce the “systems” perspective. From the civil sector data we conclude that this is not presently happening to sufficient levels. A greater focus must be placed upon involving these personnel types with the project early. Note that in chapter 5, a relationship was presented regarding the increasing engagement of operations personnel and stakeholders for developing product specifications as the project team’s comprehension of relevant prior lessons learned increases. In addition to prior lessons learned, management needs more visible channels to convey the necessity of this early cross-functional participation to its project teams for reducing project risks.

Summary of Key Findings

According on one interview respondent, we are not automatically effective communicators of risk. This is a trait that is developed over time. To measure the effectiveness of team communication, we observed the frequency of project team meetings with all members involved. It was found that these meetings were taking place on a healthy frequency. Over 82% of the time teams were meeting at least once every two weeks or more often. Frequency of team meetings was not found to be a factor for influencing schedule slips, budget overruns, or performance degradation.

Project master schedules were most frequently communicated by handouts in team meetings. Posting the schedule to a common wall was not a common approach, even for teams with substantial collocation. Use of a project website was not found to be a preferred choice for functionally separated team members. Despite the advantage of accessing a master schedule from a project website while located anywhere with a computer, generally only 30% of the time a project website was used as the primary method. There was found to be a relationship between schedule visibility and schedule slippage. The key finding is that when schedule visibility is restricted to being shown only upon request, or not shown at all, the project schedule was
delayed 100% of the time. Thus, team members must be kept consistently informed of the latest project schedule details to maintain their focus on meeting critical milestones and deadlines.

Projects used a considerable amount of customer/stakeholder involvement for developing project specifications. Key customers/stakeholders were found to be used more than operations personnel or scientists, both by the aggregate group as well as by project sector. Since organizations today recognize the need for the significant involvement of these types of personnel early in the development process, steps must be made to increase the percentage of involvement. NASA has specifically emphasized the need for operations personnel and scientists in all aspects of the project lifecycle. This research has demonstrated that this message is being conveyed through the study of prior lessons learned. As a method for reducing project risk, management needs to rigorously support this cross-functionality from the team formation stage.
Chapter 8
Identification & Control of Risk

This chapter concentrates on the identification and control of programmatic risks. These topics are explored by two sections which probe questions related to risk identification and risk control. The risk identification section examines senior manager definitions of “appropriate” risk for their organization, who was responsible for the identification and classification of risks for the projects studied, how a senior executive views a project manager that suddenly identifies a risk downstream in the product development process, the methods used for identifying risks, the primary concerns a senior manager has for project success, and the strongest positive and strongest negative impacts to a project as viewed by both senior managers and project managers. The control of risk is studied by evaluating the types of acceptable project managers for revolutionary complex systems developments, methods by which the project teams made technical decisions, project technology risk mitigation strategies, the frequency of increases to project scope, and the frequencies of system architectural and key technology reviews during the project lifecycle.

Part I: Identifying Risks
Defining “Appropriate” Risk

Senior managers were asked to qualitatively define “appropriate” risk for a complex systems project in their organization. The reader may refer to question R4 of the survey in Appendix A. The definitions were found to vary widely. However, 5 general themes could be extracted from the responses provided. Table 8.1 exhibits the 5 major categories for appropriate risk and their response frequency from the senior managers surveyed.

<table>
<thead>
<tr>
<th>Type of Appropriate Risk Definition</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs vs. Benefits Perspective</td>
<td>33.3</td>
</tr>
<tr>
<td>Acceptable to Responsible Parties</td>
<td>28.6</td>
</tr>
<tr>
<td>Quantitative Measures/Thresholds</td>
<td>14.3</td>
</tr>
<tr>
<td>Availability of Alternatives</td>
<td>14.3</td>
</tr>
<tr>
<td>Performance, Cost, &amp; Schedule Relationship</td>
<td>9.5</td>
</tr>
</tbody>
</table>

Table 8.1 Appropriate Risk Categories

The Costs vs. Benefits category contained views primarily focused on the project obtaining benefits commensurate with the size of the investment and/or the span of the objectives undertaken. These responses were more concerned with the fact that the benefits outweighed the costs, as opposed to the actual level of risks taken or investments made. This suggests that if a project can effectively raise the benefits, or lower the costs, to achieve a favorable ratio, then the project is deemed an appropriate risk. There is some of the “nothing ventured, nothing gained” philosophy from Wall Street embedded here, whereby a project can be considered a success if its return on investment (ROI) is positive. Some managers will accept an incomplete attainment of the project’s objectives for an overall ROI that furthers the longer term programmatic strategies for which the project was just one part.
The Acceptable to Responsible Parties category focuses on appropriate risk as synonymous with acceptable risk. In this fashion, risk is acceptable if it is agreed upon by the responsible parties to the project, i.e. the project manager, the stakeholders, the customers, review boards, etc. The NIAT report definition of acceptable risk epitomizes this category. According to NIAT, “Acceptable risk is the risk that is understood and agreed to by the program/project, Governing Program Management Council, and the customer as sufficient to achieve the defined success criteria within an approved level of resources.” An important aspect emphasized by both the NIAT report and the senior manager responses is the requirement of informed decision-making continuously throughout the project lifecycle. This perspective for appropriate risk suggests that projects of an organization are each unique, which lead to individual definitions that are specifically tailored on a project-by-project basis. Also critical to this emphasis is the clear communication to the responsible parties of the ramifications due to known risks, in terms of probabilities, consequences, costs, and mitigation alternatives.

The Quantitative Measures/Thresholds category attempts to define appropriate risk in terms of a measurable probability of failure, or a critical threshold by which a project risk should not exceed. Naturally, probabilities should be shown to be very small for the project to deem them appropriate, usually on the order of $<1 \times 10^6$. Thorough systems engineering approaches have been suggested to properly quantify risks in this fashion. Ultimately, the project manager or chief engineer in charge of risk management is in the best position to assess whether quantitatively specified risks make sense for the project to accept.

The Availability of Alternatives category captures the process of brainstorming to determine what can possibly go wrong, the probability of occurrences, the expected consequences of the risk, and the availability of work-around solutions to successfully mitigate the consequences to a tolerable level. Alternatives which reduce project requirements are considered appropriate if they remain within acceptable limits. A thorough, repeated application of this thought process by the project team and management will lead to a determination of appropriate risk.

The Performance, Cost, and Schedule Relationship category defines appropriate risk in terms of impacts to these interrelated aspects of the project. For example, a performance risk is considered appropriate if it can be de-scoped at a later time without negative impacts to either the cost or the schedule of the project. This requires an understanding of the de-scope options a priori and an analysis of the cost and/or schedule impact. This document assumes that safety to personnel and facilities falls under the performance classification. Therefore, a risk may be appropriate as long as it does not jeopardize safety.

Who Identifies & Classifies Project Risks
Project managers were surveyed to find out who actively participated in the identification and classification of risks to their project. The reader may refer to question R8 of the survey in Appendix B. Respondents were directed to check all of the choices which applied. Table 8.2 shows the percentage of projects which used a given type of employee to identify and classify risks. The table provides the results for both aggregate project data and by project type.

Those involved in risk identification and classification determine which risks are likely to affect the project, and then document the corresponding characteristics. They also evaluate each of the risks independently, and their interactions with other risks, sorting each into a collection of
possible outcomes. Many sources urge that risk identification and classification should not be a one-time event. Rather, it should be performed repeatedly throughout the project’s duration.

<table>
<thead>
<tr>
<th>Employee Type</th>
<th>Civil</th>
<th>Military</th>
<th>Commercial</th>
<th>Aggregated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Manager</td>
<td>88%</td>
<td>100%</td>
<td>64%</td>
<td>86%</td>
</tr>
<tr>
<td>Lead Systems Engineer</td>
<td>88%</td>
<td>88%</td>
<td>71%</td>
<td>84%</td>
</tr>
<tr>
<td>Lead Subsystem Engineers</td>
<td>73%</td>
<td>63%</td>
<td>57%</td>
<td>67%</td>
</tr>
<tr>
<td>Some Discipline Engineers</td>
<td>73%</td>
<td>75%</td>
<td>50%</td>
<td>68%</td>
</tr>
<tr>
<td>All Team Members</td>
<td>30%</td>
<td>50%</td>
<td>43%</td>
<td>38%</td>
</tr>
<tr>
<td>R&amp;QA Personnel</td>
<td>58%</td>
<td>50%</td>
<td>29%</td>
<td>49%</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>36%</td>
<td>38%</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>Senior Management</td>
<td>42%</td>
<td>63%</td>
<td>57%</td>
<td>51%</td>
</tr>
<tr>
<td>Scientists</td>
<td>45%</td>
<td>19%</td>
<td>0%</td>
<td>29%</td>
</tr>
<tr>
<td>Peer Review Board</td>
<td>48%</td>
<td>38%</td>
<td>21%</td>
<td>40%</td>
</tr>
<tr>
<td>External Review Board</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Operations Personnel</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Table 8.2 Percentages of Those Who Identify/Classify Risks by Type of Project

The expectation was for high percentages for each of the choices, nearing 100% for many of the employee types. However, only for all of the military projects was the project manager actively participating in the process. The civil projects did not involve the project manager 14% of the time. The commercial projects only used the project manager 64% of the time. The lead systems engineer was relied upon more frequently by the government projects than the commercial projects. The military projects involved all team members the most, amounting to 50% of the projects. By comparison, the civil projects only utilized the entire project team 30% of the time. The Reliability and Quality Assurance (R&QA) group personnel were found to participate either at or just above the 50% level for the government projects, while only 29% for the commercial projects. Stakeholders were used no more than 50% of the time by the three project sectors. Senior management was involved only 42% for civil projects, but ~60% for the military and commercial projects. The involvement of scientists by civil projects amounted to less than half of the time, by military projects less than 20% of the time, while commercial projects did not involve them at all. Less than 50% of any project type used peer review boards. Only one civil project cited the use of operations personnel.

Only one civil project cited the use of an external review board. Rechtin states that independent expert reviews give top management a feeling for the risk level of the decisions they are called on to make, by surfacing the major problem areas and prior decisions. They serve as a safeguard against the human tendency to solve all problems at the lowest possible levels. Solving problems at the lowest levels may seem appropriate in the context of not needlessly bothering or alarming higher management levels, however senior management needs to know what the problems were and at what levels of risk they were solved. Not only may others view the associated risks from a different level of severity, a review of prior actions facilitates the opportunity to perform a better evaluation of total system risk.
The NIAT report targets the project manager as primarily responsible for risk analysis. It also defines the R&QA group as lending both guidance and support for risk identification and classification. All team members are expected to understand their role in contributing to this process. Senior management and stakeholders (includes customers) must be clearly involved in defining acceptable risk for the project, identifying and classifying risks, and continuously managing risk. The scientists are also expected to be involved continuously with the project in this regard. Using the civil project percentages revealed by Table 8.2 as an indicator, NASA needs to improve the level of involvement by these types of employees for identifying and classifying risks.

**Sudden Risk Communication**

Senior managers were asked to provide their view of a project manager (PM) that suddenly communicates a potential risk that was otherwise unaccounted for earlier in the project lifecycle. The reader may refer to question R6 of the survey in Appendix A. Table 8.3 provides the possible options and the corresponding results.

<table>
<thead>
<tr>
<th>Option</th>
<th>How Project Manager is Viewed</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The PM is doing the right thing by bringing it to our attention</td>
<td>42.9 %</td>
</tr>
<tr>
<td>B</td>
<td>The PM is demonstrating inexperience with risk management, but has good common sense</td>
<td>23.8 %</td>
</tr>
<tr>
<td>C</td>
<td>The PM is being proactive and is demonstrating effective risk management</td>
<td>23.8 %</td>
</tr>
<tr>
<td>D</td>
<td>Other</td>
<td>9.5 %</td>
</tr>
<tr>
<td>E</td>
<td>The PM is weak at risk management and is likely to fail with this project</td>
<td>0 %</td>
</tr>
</tbody>
</table>

Table 8.3 Views of a Project Manager Who Suddenly Communicates a Risk

No senior managers responded specifically with option E, i.e. the project manager is weak at risk management and the project will likely fail. This can be considered a good sign that senior managers view it acceptable to uncover a hidden risk downstream. However, 9.5% of the respondents used the “other” category to state that their view is dependent on the circumstances. If it was reasonable to identify the risk earlier, then the PM is either weak or inexperienced with risk management. Almost 24% of the respondents chose option B, i.e. the PM is inexperienced but is demonstrating common sense. This choice provides a more positive view of inexperience than option E. An equal number of respondents chose option C, i.e. the PM is proactive in risk management. This choice suggests that the senior manager recognizes the fact that not all risks will be identified early enough, and that the PM must be executing some form of continuous risk management to identify a new risk at this stage. The most popular response was option A (43%), i.e. the project manager is doing the right thing by bringing it to the attention of senior management. The insight here is that a senior manager views this situation as a display of neither weak nor strong risk management, but places more of an emphasis on the communication of the project condition. Depending upon the communication atmosphere that senior management creates for its project managers, a PM may or may not feel the pressure to keep this information to a confined level, in fear of being viewed negatively.
Risk Identification Methods

Senior managers were asked to describe the types of specific methods used in their organization to identify risks. The reader may refer to question R10 of the survey in Appendix A. The methods are grouped into three categories: quantitative methods, informal procedures, and standard processes. Table 8.4 highlights the findings with respect to these categories. Each entry provides the number of instances in parentheses.

The NASA Systems Engineering Handbook points out that the techniques used must be chosen to best fit the unique requirements of the project. The Handbook cites expert interviews, independent assessments, prior project risk templates, lessons learned, FMEA’s, digraphs, and fault trees as the recommended approaches. Although respondents cited the PRA method and risk tracking procedures, these are risk analysis/assessment techniques. Smith and Reinertsen feel that the development of a risk management plan is vital for proactively uncovering important risks and effectively planning for them at project initiation. The overall thoroughness for which any of these identification methods is accomplished has a major bearing upon the effectiveness of risk management for a project.

<table>
<thead>
<tr>
<th>Quantitative Methods</th>
<th>Informal Procedures</th>
<th>Standard Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure Modes and Effects Analysis (FMEA)</td>
<td>PM Evaluations of Risks Suggested by Team Members (4)</td>
<td>Peer Reviews (3)</td>
</tr>
<tr>
<td>Probabilistic Risk Assessment (PRA) (6)</td>
<td>Risk Lists from Other Projects (4)</td>
<td>Risk Management Plans (2)</td>
</tr>
<tr>
<td>Fault Tree Analysis (4)</td>
<td>Disciplined Risk ID &amp; Tracking Procedures (4)</td>
<td>Independent Panel Assessments (1)</td>
</tr>
<tr>
<td>Risk Matrices (2)</td>
<td>Expert Consultations (2)</td>
<td>Verification Tests (1)</td>
</tr>
<tr>
<td>Operational Hazard Analysis (OHA) (2)</td>
<td>Mentoring Dialogs (1)</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.4 Risk Identification Methods Used by Projects

Top Three Project Concerns of Senior Managers

Senior managers were solicited to gather their top three concerns regarding project success. The reader may refer to question R9 of the survey in Appendix A. Several themes emanated from an evaluation of this qualitative data set. These concerns are illustrated in Figure 8.1.

The top concern was distributed among the categories of managing requirements, human resources, and technical capability of the system. Requirements management concerns included such things as meeting the project’s success criteria, handling changing requirements, and thoroughly understanding project requirements. Human resources concerns centered around the ability of the project manager, sufficient staffing, and the quality of project teams. Concerns regarding the technical capability of the system included its successful technical performance, and operational safety.

The 2nd highest concern on the minds of senior managers was primarily the financial budget. Aspects of this included realistic cost estimates, adequate budget reserves, and a balance of scope.
with available financial resources. The 3rd highest concern included both cost and schedule, targeting the adequacy and stability of each.

![Diagram: Top 3 Concerns for Project Success]

- **Top Concern**: Managing Requirements
- **2nd Concern**: Human Resources
- **3rd Concern**: Financial Budget

Technical Capability of System

**Figure 8.1 Top 3 Concerns for Project Success**

**The Strongest Positive and Negative Impacts to a Project**

Both senior managers and project managers were polled to determine their thoughts on what the strongest positive and strongest negative impacts are to a project. The reader may refer to questions R14 and R15 of the survey in Appendix A, and questions G1 and G2 of the survey in Appendix B. These strongest impacts are illustrated in Table 8.5. Each entry provides the number of instances in parentheses.

<table>
<thead>
<tr>
<th>Senior Managers</th>
<th>Project Managers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongest Positive Impact</td>
<td>Strongest Positive Impact</td>
</tr>
<tr>
<td>Strong Project Leadership (10)</td>
<td>Team Quality &amp; Commitment (24)</td>
</tr>
<tr>
<td>Open, Clear Communications (4)</td>
<td>Adequate &amp; Stable Resources (6)</td>
</tr>
<tr>
<td>Changing Requirements (3)</td>
<td>Strong Customer Relationship (6)</td>
</tr>
<tr>
<td></td>
<td>Senior Management Commitment (4)</td>
</tr>
<tr>
<td>Insufficient &amp; Unstable Resources (6)</td>
<td>External Influences (12)</td>
</tr>
<tr>
<td>Poor Project Leadership (5)</td>
<td>Changing Requirements (9)</td>
</tr>
</tbody>
</table>

**Table 8.5 Strongest Positive and Negative Impacts to a Project**

The strongest positive impacts to projects perceived by senior managers are grouped into two major subject areas: Strong Project Leadership, and Open, Clear Communications. The strong project leadership theme was stated by a majority of the senior manager respondents. This theme focuses on the value for outstanding leadership qualities of the project manager, where his/her technical, managerial, and communicative abilities make the difference in successfully coordinating the project team to meet the objectives and requirements of the project. The open, clear communications theme emphasizes the honest, clear communication among all personnel involved with the project, both internal and external to the project organization. This includes clearly stating project goals, objectives, scope, and all resources agreed upon. This also contains
the delivery of constructive feedback during the development process, as well as moral and tangible support from upper management.

The strongest negative impacts to projects perceived by senior managers are grouped into three major subject areas: Insufficient and Unstable Resources, Poor Project Leadership, and Changing Requirements. The insufficient and unstable resources theme includes projects which experience a lack of sufficient staffing, budgets, and completion time. It also consists of the project instability due to changes in resources during the project lifecycle, and intra-project competition for the same pool of personnel and financial resources. The poor project leadership theme highlights the project manager who may lack adequate leadership skills, lack sufficient interpersonal skills, or may also be ineffective at negotiating the dynamics of cross-functional teams. The changing requirements theme focuses on the instability of requirements as well as understanding the ramifications of requirements changes downstream in the product development process. This section also includes the changing of strategic priorities by the organization.

The strongest positive impacts to projects perceived by project managers fall into four major subject areas: Team Quality and Commitment, Adequate and Stable Resources, Strong Customer Relationship, and Senior Management Commitment. The team quality and commitment theme was stated by an overwhelming majority of the project manager respondents. This theme included such aspects as: positive team member attitudes; team member excitement for the project; a well-qualified, synergistic team; strong technical competence; a hard-working team committed to completing the project despite having to face some obstacles and to work long hours; and excellent team collaboration. The adequate and stable resources theme includes the provision of ample funding, staff, and schedule to start the project, as well as a stable resource environment throughout the duration of the project. The strong customer relationship theme emphasized strong interactions with product customers at all levels of engineering and customer participation during all phases of the project lifecycle. Customers clearly stating requirements, while proposing those which were realistic, was also an important consideration. Also suggested was the willingness by both the organization and the customer for the customer to be engaged with the project on-site. Senior manager commitment was also recognized as a positive influence. Project managers felt that support by upper level management was essential to maintain critical staffing levels, and to reach agreement on the project’s vision, goals, and level of priority.

The strongest negative impacts to projects perceived by project managers are grouped into three major subject areas: Insufficient and Unstable Resources, External Influences, and Changing Requirements. The insufficient and unstable resources theme includes factors such as a lack of sufficient staffing, budgets, and completion time. It also includes a loss of key personnel to other projects, a deficiency in skills, excessive personnel changes, difficulty in hiring, unrealistic budgets and schedule, fluctuations in funding levels throughout the project lifecycle, and inadequate development tools. The external influences theme cited project impacts due to public perceptions of failure, politics and policies, mandates from higher authorities, and delays due to spacecraft launch vehicle problems. The changing requirements theme highlighted continuous changes to project scope, requirements creep, the rapidity of changing requirements, and changes driven by the customer or by incomplete system concepts.
Part II: Controlling Risks

Types of Acceptable Project Managers

Senior managers were asked to provide their view of the types of project managers (PM) that would be acceptable to lead a complex system development that is dependent upon a significant number of emerging technologies. The question was posed because the situation often exists where the existing skills of the project managers available do not offer a perfect fit for the assignment. Thus, a critical management decision has to be made on the types of skills that senior managers would find acceptable for this assignment. The reader may refer to question R1 of the survey in Appendix A. Table 8.6 highlights the types of acceptable project managers and the corresponding results from the survey. The respondent was instructed to select all of the choices that applied.

Since every choice of PM has its advantages and disadvantages, no one option was checked 100% of the time. The dominant option was A, the veteran PM, with a two-thirds (66.7%) response rate. One-third of the respondents may have not selected the veteran PM for fear of this person being too conservative and set in their ways to think enough “out of the box.” It is to be expected that novel approaches and innovations will be necessary for this type of project, in contrast to applying the same proven methodologies that have earned the PM their successes in the past. Option B came in a close second, selected 62% of the time, yielded a high vote of confidence from the senior manager population. This may be due to the respect he/she has earned as being among the best and brightest, giving the senior managers the impression that with the proper mentoring, this type of PM is likely to be quite successful. With the ability to learn quickly carries the possibility that this type of PM will be up on the latest and greatest approaches available for the challenge at hand.

<table>
<thead>
<tr>
<th>Option</th>
<th>Types of Acceptable Project Managers</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Only a veteran PM who has numerous successes under his/her belt is appropriate for this position.</td>
<td>66.7 %</td>
</tr>
<tr>
<td>B</td>
<td>The PM is among the best and brightest employees in the organization. The PM learns everything quickly, but is still somewhat inexperienced at managing this type of endeavor.</td>
<td>61.9 %</td>
</tr>
<tr>
<td>C</td>
<td>The PM demonstrates sound personnel management skills but is not that strong technically. The PM relies mainly on others to make tough technical decisions.</td>
<td>33.3 %</td>
</tr>
<tr>
<td>D</td>
<td>The PM has substantial technical product development experience but has little or no real management experience.</td>
<td>14.3 %</td>
</tr>
</tbody>
</table>

Table 8.6 Senior Manager Views on Types of Acceptable Project Managers

Option C was selected one-third (33.3%) of the time, while option D was selected only 14% of the time. One possible interpretation of these response rates is as follows. Over 85% of the respondents did not select option D, the technical PM without sufficient management skills. This suggests that management skills are valued more than technical skills when confined to selecting between options C and D. This is confirmed by seeing that over double the response rate occurred for option C than option D. This finding defies two common management preparation theories. The first theory is that the best technical project managers were previously technical engineers that spent between 5 to 15 years becoming a well-respected technical authority through
direct experience, and in the process were groomed by their superiors for future management roles. The second theory emanates from one interview respondent who suggested that one can learn the interpersonal aspect of the job quickly, but not the technical aspect. This is especially true for organizations that offer a plethora of short courses on leadership, communication, and the like. If one hasn’t had sufficient experience building hardware and software, then it is likely they will not be effective at managing those that do.

If an organization has the proper infrastructure to support the deficiencies of project managers, then all options to this question can be deemed acceptable. According to one interview respondent, the NASA tendency is to select the veteran project manager if at all possible. However, regardless of experience, no project manager should operate in a vacuum. One can never become skilled enough to afford passing up the benefit derived from employee interactions.

**Making Technical Tradeoff Decisions**

Project managers were asked to describe the method most often used to make technical tradeoff decisions for their project. The reader may refer to question R5 of the survey in Appendix B. Table 8.7 highlights the choices of methods and the corresponding survey results.

<table>
<thead>
<tr>
<th>Technical Decision Method</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>By inputs from the project manager, lead systems engineer, and several other lead personnel</td>
<td>59.7%</td>
</tr>
<tr>
<td>By total team consensus</td>
<td>14.5%</td>
</tr>
<tr>
<td>By stakeholder review</td>
<td>14.5%</td>
</tr>
<tr>
<td>By team majority vote</td>
<td>3.2%</td>
</tr>
<tr>
<td>By project manager decision</td>
<td>3.2%</td>
</tr>
<tr>
<td>Imposed from a higher authority</td>
<td>3.2%</td>
</tr>
<tr>
<td>By peer review</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

**Table 8.7 Methods for Making Technical Decisions**

The most common method for making technical tradeoff decisions was by inputs from the project manager, lead systems engineer, and several other lead personnel (60%). In contrast, only 3.2% of the time were technical decisions made solely by the project manager. Note that the project manager only method occurred when the size of the project teams exceeded 100 members, there was a 25/75 split of company employees to contractors, and only some collocation was in effect. This tells us that under these circumstances, decision-making by a single individual may have been most prudent for project efficiency. Almost 15% of the projects used either a team consensus or a stakeholder review as their primary method for resolving tough technical decisions. The team consensus approach far outperformed the “reduced” version of team majority voting by over a factor of 4. As team size increases, the effectiveness of achieving a consensus declines rapidly. This is confirmed by the data since project teams executing a consensus had a team size of less than 25 members. The stakeholder review approach indicates a strong relationship with the stakeholders, and either frequent communications or an unusually small number of tough technical decisions to make. By comparison, only one project used a peer review process. Note that this project team contained less than 10 members. One might postulate from this data that it is easier to assemble a group of stakeholders than organizational peers, even
though this is intuitively unlikely. Either way, since a complex systems project is likely to have many tough technical tradeoffs to make, it doesn’t appear prudent to implement a review process for every decision. Reviews are helpful to obtain objective perspectives when the timeliness of having to commit to a decision coincides with the date of the review. Two projects got their tradeoff decisions imposed from a higher authority, which may indicate a lack of project manager empowerment, or a politically driven force in action.

**Technology Risk Mitigation Strategy**

Project managers were queried to determine the risk mitigation strategy in place for their project’s enabling technology developments. The reader may refer to question T1 of the survey in Appendix B. Table 8.8 provides the proposed strategies and the corresponding results from the survey.

The most popular strategy implemented was to develop one or more backup technologies in parallel (38.3%). The next most popular strategy was to adapt the most compatible COTS technology product as the alternative (21.7%). Note that more projects (15%) used a strategy of requesting a budget increase to protect against delays or problems, than to delay the schedule until the technology was successfully delivered (11.7%). This implies that schedule was deemed more important than cost. Two particularly interesting “other” suggestions were to relax project requirements, and to add a “prototype” phase to the project lifecycle to guarantee a higher maturity level for the technologies in the later project phases. The first suggestion can be viewed as including strategies C and E as components. The second suggestion eludes to the technology pipeline approach described by the NIAT report, where technologies are developed independently and infused into projects that can make use of them when they become mature enough.

<table>
<thead>
<tr>
<th>Option</th>
<th>Technology Mitigation Strategy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Develop one or more backup technologies in parallel of critical new technologies for ready substitution if necessary</td>
<td>38.3 %</td>
</tr>
<tr>
<td>B</td>
<td>Adapt the most compatible commercial-off-the-shelf product available as the resolution</td>
<td>21.7 %</td>
</tr>
<tr>
<td>C</td>
<td>Request a budget increase to protect against delays in delivery or problems in meeting required performance levels</td>
<td>15.0 %</td>
</tr>
<tr>
<td>D</td>
<td>Other</td>
<td>13.3 %</td>
</tr>
<tr>
<td>E</td>
<td>Delay the project schedule until the technology is successfully delivered</td>
<td>11.7 %</td>
</tr>
</tbody>
</table>

*Table 8.8 Technology Mitigation Strategies*

**Increase of Project Scope**

Project managers were asked to identify whether their project’s scope was ever increased beyond their personal control. This includes the exercise of power by senior executives, due to external influences from stakeholders, or the like. The reader may refer to question R3 of the survey in Appendix B. Almost three quarters of the projects (71%) did have such increases in
scope. This suggests that for this project population, the project manager is placed into an undesirable situation. Senior managers must support a balance of project scope with available resources, and protect the project manager from these negative external influences to maintain favorable chances for project success.

**Use of System Architecture and New Technology Peer Reviews**

The number of system architecture peer reviews that were implemented prior to a project committing to a single point design was studied. The number of peer reviews that were implemented for the project’s enabling technologies during the early conceptual design phases of the lifecycle was also probed. Additionally, project managers were asked to provide the number of these new technology peer reviews that they now felt were necessary, after project completion. The reader may refer to questions R2, T5 and T6 of the survey in Appendix B. The question regarding system architecture peer reviews was posed to determine the frequency that organizations subject their product architecture concepts to a review of peers. Such peer reviews aid in the downselecting process to arrive at a single architectural concept. The questions regarding enabling technology peer reviews were asked to determine how frequently organizations were reviewing their key technology developments by peers, and how often project managers felt they should be conducting. Technology peer reviews aid in the identification of development problems early, and support the application of risk mitigation alternatives. One note of caution to the reader is the ambiguity associated with the measurement of a technology peer review. The survey question did not specify whether one review covers only a single technology or all project technologies collectively as a group. Future work can include contacting the project sources to confirm the intention, or reissuing an updated survey. For our purposes, one review includes coverage for the project’s entire set of enabling technologies.

![Number of System Architecture Peer Reviews Used for Projects](image)

**Figure 8.2 Number of System Architecture Peer Reviews Used for Projects**

Figure 8.2 illustrates the number of system architecture peer reviews implemented by project type. Values ranged from 0 to 50 reviews. The aggregate mean number of peer reviews was 4.67. However, from Figure 8.2 we see that by far, the most popular number of peer reviews in practice was either 2 or 3, depending on project sector. Both the commercial and civil government projects implemented a number of peer reviews which exceeded 20. The military sector did not exceed 6 peer reviews for a project. The system complexity, duration, and scope
of military and civil government projects warrant a sufficient number of system architectural peer reviews. Any insufficiency in the numbers found here may be due to the conducting of formal reviews in the lifecycle.

Figure 8.3 exhibits the frequencies of enabling technology peer reviews used. Values ranged from 0 to 100 reviews. The aggregate mean number of peer reviews implemented was 5.03. However, from Figure 8.3 we see that by far, the most popular number of peer reviews in practice was either 1 or 2, depending on project sector. Note that both the commercial and military government projects implemented a number of technology peer reviews exceeding 25. The largest number of civil government peer reviews totaled 5. Due to the uncertainty of new technology development, a sufficient number of peer reviews is a wise investment in time and effort for mitigating cost, schedule, and performance risk to the project.

40% --------------- 35% - 30% Military 25% 20% Commercial 15% 10% 5% 0% 1 2 3 4 5 6 12 25 50 100 Number of Technology Peer Reviews Implemented

Figure 8.3 Number of Technology Peer Reviews Implemented by Projects

Figure 8.4 highlights the frequencies of enabling technology peer reviews deemed necessary. Values ranged from 0 to 50 reviews. The aggregate mean number of technology peer reviews necessary was 4.16. In contrast, Figure 8.4 shows us that the most common frequency desired is 2 to 3, depending on project sector. Note that only the commercial projects suggested a number greater than 5. The largest number of early technology peer reviews considered necessary by military and civil government projects was 5. This is a bit surprising since government projects are the ones which usually contain the largest number of enabling technologies to negotiate. One interview respondent claimed that project teams felt they were subjected to too many reviews. If they spend most of their time preparing for reviews, then there is never ample time to develop the system. One may postulate that this attitude affected the number of peer reviews suggested as necessary. Rechtin claims that reviews, whether or not well-liked by the project team, serve to maintain discipline, encourage proper documentation, ensure accountability for the decisions that are made, and aid in reducing the risk of failure.
Senior managers have a variety of ways for expressing what appropriate risk means to them. This may be partly because the subject of risk management is not that easy to define, not to mention clearly understand. This is further exacerbated by the number of risk components for today’s complex system developments, e.g., performance, safety, cost, schedule, technological, organizational, and political risks. In addition, individuals each vary in their level of risk aversion, and the same individual can possess differing levels of risk aversion depending upon what is at stake. Appropriate risk definitions for the senior manager population are primarily focused on a costs vs. benefits perspective, and that which is accepted by the responsible parties of the project. The costs vs. benefits view considers appropriate risk to be that which allows for a positive expected return on investment for the project. Alternatively, risk accepted jointly by the project manager, project team, the customers and stakeholders, and senior management councils constitutes appropriate risk. Note that this latter definition of appropriate risk matches the NIAT Report definition of acceptable risk.

During the early phases of a project, risks are primarily identified by the project manager, the key project team members, the Reliability and Quality Assurance group, senior management, and in some cases the scientists and peer review boards. The data supports the need to emphasize more involvement by the entire project team, the stakeholders, the scientists, and the operations personnel. The NIAT report states that team members must fully understand their role in identifying and controlling risk. Mandatory training for technical project employees would help to raise the awareness as well as instruct how to approach identifying and classifying risks. Conrow states that in order for risk management to be effective, the team members must consider it as part of their daily decision-making process. Suitable incentives should be provided for those who identify potential project risks, to encourage this behavior. The NIAT report also recommends the support of the R&QA group to provide guidance for risk identification and development of risk management plans. Hence, steps should be taken to promote continuous project team involvement with the R&QA group. Since the statistics show that only half of the
projects made use of these support personnel, organizations may not be taking full advantage of their available risk management resources.

There are a variety of senior manager reactions to project managers which identify a risk at some downstream point in the project lifecycle. The most common response is that the project manager is doing the right thing by communicating it to senior management. This can be viewed as a neutral reaction to the project manager's skill at risk management. This also tells us that the senior manager appreciates communication among all things. Welcoming communications is further substantiated by the senior managers identifying open, clear communications as one of the most positive impacts to a project. Along these lines, the NIAT report instructs that project success criteria be made clear at all levels in order to assist risk decision-making.

There are a variety of risk identification methods employed by the projects, divided among quantitative methods, informal procedures, and standard processes. Many of the techniques cited match those recommended by the NASA Systems Engineering Handbook. A combination of these methods should be employed to a project. The NIAT report suggests that critical risk lists must be generated by projects. Four projects surveyed noted the use of risk lists from other projects in order to identify risks.

The top concerns a senior manager has for project success include managing requirements, human resource issues, technical system performance, and adequate budgets and schedules. Meeting project success criteria, effectively handling changing requirements, and fully understanding project requirements constituted the concerns for requirements management. Human resource issues focused on project manager ability, sufficient staffing, and project team quality. Similarly, we observed that senior managers significantly emphasize strong leadership by the project manager as the greatest positive impact to a project, while project managers significantly emphasize the quality and commitment of their team. Note that the requirement for strong project manager leadership is a recurring theme throughout the Air Force, NRO, DARPA, and NASA. Project managers also cited strong positive impacts to include adequate and stable resources, and a strong customer relationship. Both senior managers and project managers agree that the strongest negative impact to a project is insufficient and unstable resources. The loss of key personnel is a contributing factor to this insufficiency, and has been a problem for the Air Force, the NRO, as well as for NASA. Both types of managers also identified changing requirements as another negative impact. Senior managers cite poor project leadership as a negative impact, highlighting insufficient interpersonal skills and ineffectiveness of negotiating the dynamics of cross-functional teams. Project managers emphatically cite external influences to be a strong negative impact to a project. On the contrary, senior managers failed to recognize external influences as a significant project risk. One of the most important roles a senior manager can play to help ensure the success of the organization’s projects is to aid in filtering the disruption that external influences levy upon the project manager.

Project managers cite senior manager commitment as a positive impact to a project. The stability of resources is certainly tied to this commitment. Smith and Reinertsen articulate that if top management echoes their support for a project to various parts of the organization, the lower levels of the hierarchy quickly get the message that the project is important. Since senior
managers may be unaware of the quality of their support to a project, obtaining critical feedback directly from the project manager on how they are doing may be necessary.

Open, clear communications is a concern expressed by senior managers in several survey instances. Project managers do not cite this with equivalent vigor, possibly because from their position, it does not appear to be much of an issue. While wrapped up in the day-to-day operations of the system development process, shortfalls in communication may not be readily visible to the project manager. Discussed earlier in this chapter, effective communication skills by the project manager was identified by senior managers as the critical component when a potential risk suddenly surfaces. Smith and Reinertsen recommend the creation of robust communication channels by promoting contact at many levels of the organization. Every type of communication tool should also be utilized. Conrow suggests to use an electronic risk management database when practical. Independent of the technology used, all risk analysis results should be clearly documented and communicated to the proper management individuals.

The type of acceptable project manager for leading a revolutionary complex system development is dependent upon the existing support infrastructure. Independent of such a support system, the most comforting choice by a senior manager is a veteran project manager with numerous past successes. A potential downside to this selection is that a seasoned veteran may be resistant to thinking “out of the box,” and exhibit too strongly a risk-averse attitude. Another top choice is the inexperienced project manager who demonstrates the ability to learn quickly. Senior managers feel that with the proper mentoring in place, this type of leader will be quite successful. A key finding was that senior managers surprisingly valued sound management skills over strong technical skills for leading this type of project, when faced with having to choose between the two traits. This is contrary to the management model which grooms star technical performers for 10-15 years before making them managers. It also suggests that the necessary technical skills can be picked up after becoming a manager, instead of vice-versa.

The most common method for making tough technical project decisions is by involving the project manager, the lead systems engineer, and several other project team leads. Two other popular methods were by total team consensus, and by stakeholder review. Team consensus was used for project teams totaling less than 25 members. Decisions made solely by the project manager occurred when the project team size exceeded 100 members, the team was dominated by support contractors, and the majority of the company team members were located in their functional organizations.

The most common technology risk mitigation strategy was to develop one or more backup technologies in parallel of the high risk technology. The second most popular strategy was to adapt available commercial-off-the-shelf products as a substitution for the failed revolutionary technology. A strategy to increase the budget in order to protect against delays in delivery was preferred over delaying the project schedule until the technology was ready. The implication here is that schedule appears more important than cost for new technology development. The NIAT report describes an ambitious technology pipeline strategy whereby a balance of technologies at varying levels of maturity are available for project selection. A successfully implemented pipeline approach will be on a par with the reliance upon backup technologies as a means to mitigate high risk technologies.
Almost three-fourths of the projects have their scopes increased beyond the project manager's control. This is one form of external influences impacting a project, and raising the probability for failure.

Two to three system architecture peer reviews were most commonly implemented during the early stages of projects. The commercial and civil government sectors exercised in excess of 20 reviews for some projects. Six reviews were the highest number the military sector used for a project. The most popular number of new technology peer reviews in practice was one or two. The commercial and military government sectors implemented in excess of 25 peer reviews for some projects. The largest number of civil government reviews for a project was five. Two to three new technology peer reviews were most commonly considered necessary by projects was either 2 or 3. The military and civil government sectors did not specify a requirement for more than 5 reviews. In comparison, the commercial sector considered up to 50 reviews to be essential. Interestingly, an inadequate number of reviews were frequently cited in the NASA mission failure reports.
Chapter 9

Project Progress Measurement

This chapter focuses upon the methods by which a project can measure their progress. For the projects surveyed, the following aspects were studied: The specific metrics used to measure the project’s progress; the management rigor applied to addressing project meeting action items; the effect of schedule pressure on the team members; the frequency and duration of schedule slips; the frequency and type of performance degradation or de-scopes implemented; the percentage of budgets increased from their initially defined allocations; and the perceived impact by project managers of project budget instabilities.

Metrics Used to Measure Project Progress

Project managers were asked to qualitatively specify the types of performance metrics used to measure their project’s progression. The reader may refer to question R10 of the survey in Appendix B. A variety of different metrics were stated. Table 9.1 illustrates the most common responses and the number of instances they were cited.

<table>
<thead>
<tr>
<th>Metric Type</th>
<th>Number of Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget/Schedule Milestone Tracking [Actual vs. Planned]</td>
<td>42</td>
</tr>
<tr>
<td>Technical Performance Requirements Met</td>
<td>16</td>
</tr>
<tr>
<td>Progress Reviews</td>
<td>10</td>
</tr>
<tr>
<td>Number of Tasks Completed / Left to Complete</td>
<td>5</td>
</tr>
<tr>
<td>Risk Retirement Tracking</td>
<td>5</td>
</tr>
<tr>
<td>Technical Margins / Resource Reserves Tracking</td>
<td>4</td>
</tr>
<tr>
<td>Number of Discrepancy Reports</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 9.1 Types of Metrics Used to Measure Project Progress

Budget and Schedule Milestone Tracking were the unanimous favorite type of metrics used. This category includes both formal methods (e.g. Performance Measurement System) and informal methods of tracking either weekly or monthly. Of the 42 instances indicated, 9 of the responses made specific mention of the Earned Value System to track budget vs. schedule. In contrast to cost and schedule, the measurement of technical performance requirements that were met was a metric stated on 16 occasions. Progress reviews were also a rather popular methodology used. This category includes monthly reviews to senior management, independent assessment team reviews, customer run reviews, and peer reviews consisting of both internal and external members. Keeping track of the number of project tasks completed, or conversely, the number left to complete, was used by 5 of the projects in the data set. Risk retirement was also used in equal frequency. Worth noting was the tracking of technical margins (e.g. mass, weight, electrical power, data storage) and/or resource reserves (budget, schedule, manpower). Also worth mentioning was the number of discrepancy reports as an indicator for how well the project was doing.
Rigor of Addressing Action Items

Project managers were probed to determine the amount of rigor applied to closing project meeting action items on time. The reader may refer to question B8 of the survey in Appendix B. Table 9.2 illustrates the results by the aggregate project group and by project sector. For 89% of the aggregate cases, 50% or more of the action items were closed on time. For 48% of the aggregate cases, 75% or more of the action items were closed on time. Ten projects (16%) actually cited closing action items on schedule 100% of the time. We see all three project sectors most frequently close 75% of their actions items on schedule. Of the three sectors, the civil sector appears to have demonstrated the best overall performance.

<table>
<thead>
<tr>
<th>% Action Items Closed on Schedule</th>
<th>Project Type</th>
<th>Civil</th>
<th>Military</th>
<th>Commercial</th>
<th>Aggregated</th>
</tr>
</thead>
<tbody>
<tr>
<td>~100%</td>
<td></td>
<td>18.2%</td>
<td>12.5%</td>
<td>14.3%</td>
<td>15.9%</td>
</tr>
<tr>
<td>~75%</td>
<td></td>
<td>51.5%</td>
<td>43.8%</td>
<td>42.9%</td>
<td>47.6%</td>
</tr>
<tr>
<td>~50%</td>
<td></td>
<td>18.2%</td>
<td>31.2%</td>
<td>35.7%</td>
<td>25.4%</td>
</tr>
<tr>
<td>~25%</td>
<td></td>
<td>9.1%</td>
<td>12.5%</td>
<td>7.1%</td>
<td>9.5%</td>
</tr>
<tr>
<td>~0%</td>
<td></td>
<td>3.0%</td>
<td>0%</td>
<td>0%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Table 9.2 Rigor of Meeting Action Items Closure

There is a significant Pearson correlation between action items closure and schedule slippage. As the percentage of on-time closure of action items improves, the likelihood of project schedule slippage decreases. Table 9.3 exhibits the decreasing percentage of projects that slipped their schedule as the rigor to action items closure was improved.

<table>
<thead>
<tr>
<th>Project Action Items Status</th>
<th>% of Projects that Slipped Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% closed on schedule</td>
<td>100%</td>
</tr>
<tr>
<td>25% closed on schedule</td>
<td>100%</td>
</tr>
<tr>
<td>50% closed on schedule</td>
<td>75%</td>
</tr>
<tr>
<td>75% closed on schedule</td>
<td>50%</td>
</tr>
<tr>
<td>100% closed on schedule</td>
<td>30%</td>
</tr>
</tbody>
</table>

Table 9.3 Likelihood of Schedule Slippage vs. Rigor of Action Items Closure

There is also a correlation between action items closure and team leader authority. As team leader authority is increased through the range of lightweight to full authority, the percentage of action items closed on time increases. The data specifically shows that as long as the team leader either heavyweight or full authority, 50% or more of a project’s actions items are closed on schedule. Figure 9.1 provides the scatter plot for the relationship between these two project factors. The regression line in the plot points out that as you increase the level of team leader authority one step, the percentage of action items closed on schedule improves about 7%. Since the maximum range of authority change possible is from lightweight to full status, this data suggests that the maximum increase of action items closed on time that can be expected is ~21%.
Project Managers were asked to state their view on how often their project team members were under pressure to meet critical deadlines, to either keep the project on schedule or to make up time for being behind schedule. The reader may refer to question S5 of the survey in Appendix B. Table 9.4 illustrates the extent of schedule pressure by project type.

<table>
<thead>
<tr>
<th>Degree of Schedule Pressure</th>
<th>Project Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Civil</td>
</tr>
<tr>
<td>Always</td>
<td>36.4%</td>
</tr>
<tr>
<td>Frequently</td>
<td>48.5%</td>
</tr>
<tr>
<td>Sometimes</td>
<td>15.2%</td>
</tr>
</tbody>
</table>

Table 9.4 Project Team Member Schedule Pressure

Over 84% of the time, aggregate project team members were either always or frequently under pressure. Team members rarely under schedule pressure occurred for only one project (1.6%), and no projects claimed to be never under pressure. Taking the position that being always or frequently under schedule pressure is a significant performance concern, then civil project faced this 85% of the time, military projects faced it 81% of the time, and commercial projects faced it 86% of the time. What may explain the fact that commercial projects experienced the most pressure of the three sectors is the pressure for “time to market” delivery.
All in all, each sector’s projects are experiencing far too much schedule pressure, indicating the present day burden upon technical employees in producing complex system products.

**Schedule Slip**

Projects were examined for whether they experienced any schedule slip from their original baseline schedule, and the duration of the slip when it occurred. This is one measure of the project performance in terms of meeting its schedule goal. The reader may refer to question S7 of the survey in Appendix B. An aggregate of 59% of the projects did experience some form of schedule slip. For the 34 of the 36 delayed projects that specified the duration of the slip, almost 30% of them experienced a slip exceeding 1 year. The aggregate mean slip duration for the project set was 15.29 months. Figure 9.2 exhibits the slip durations by project sector. A six month slip was the most common duration for commercial projects. Military projects commonly slipped between 4 and 9 months. Civil projects most frequently slipped either 8 months or 24 months. The longest slip observed in the commercial, civil, and military sectors are 2 years, 5 years, and 12 years, respectively. The considerably longer slip durations experienced by the government projects are in indication of their typically lengthier project lifecycles in comparison to commercial projects. Also, project slips of 5 years or more must not be facing “time to market” issues!

**Figure 9.2 Length of Project Schedule Slips**

There is a relationship between team leader authority and schedule slip. As team leader authority increases, the probability for a schedule slip reduces. The project data set shows that as team leadership is increased from lightweight to full authority status, the percentage of projects experiencing a slip is decreased from 71% to 47%. Table 9.5 displays the results.
The project lifecycle stage that the highest risk technologies began funding was investigated for a possible relationship to schedule slippage. The postulation is that as technologies first begin funding later in the project lifecycle, the likelihood for schedule slip increases. Although the data shows there is evidence of such a trend, the correlation is not statistically significant. Therefore, further investigation is required in future work. Figure 9.3 illustrates the data relationship between these two project factors.

Figure 9.3 Schedule Slip as a Function of the Phase Technologies Began Funding

Performance Degradation

Projects were assessed for any performance degradation or de-scopes required from the original set of performance requirements. This is one measure on how well the project performed in terms of its functional performance goals. The reader may refer to question R9 of the survey in Appendix B. Table 9.6 illustrates the frequency of performance degradation for the aggregate project group and by project type. Some form of performance degradation was experienced for 48.4% of the aggregate projects. The commercial sector experienced the largest percentage of degradation. Table 9.7 points out the most popular causes for performance degradation of the projects surveyed.
Insufficient resources (e.g. budget, staffing, time) for the original system performance goals was one of the top causes for project de-scope. Performance requirements had to be relaxed to meet the existing budget, staff, or schedule. Technical limitations were also equal in cause. Limitations to system operation were due to such causes as a hardware failure during operation, an assembly error that was discovered too late, or an inability to meet a technical requirement during development. A change to project scope or changing requirements throughout the project lifecycle created budget or schedule overruns for six projects. A reduction in product features or relaxation in performance was needed to fall under cost or schedule constraints. For two of the projects, key new technologies were not successfully delivered in time. Changes to the project goals resulted.

The relationship between performance degradation and schedule slip was assessed. Of the 72.4% of the projects that did experience a schedule slip, some form of performance degradation occurred. However, for the projects that experienced no performance degradation, the likelihood of a schedule slip was 50/50. This tells us that performance problems are likely to cause a schedule slip, assuming that the project is taking the time to mitigate the impact in some way. But schedule slips are not caused only by performance failures.

There was no identified correlation between performance degradation and increase in project scope. Project scope was increased 70% of the time whether or not there was performance degradation. A cautionary note to the reader is that the question probing increases to project scope was specific to increases occurring only due to circumstances beyond the project manager’s control.

Multivariate analysis was performed to search for any association between performance degradation and the collective influences from team leader authority, amount of collocation, project lifecycle duration, the distribution of team company employees to support contractors, the number of enabling technologies incorporated into the project, and the impact of any budget instability. Binary logistic regression was used, setting performance degradation as the dependent variable and the remaining parameters as covariates. It was found that as the duration of the project increases, the likelihood of performance degradation rises, as long as budget instability is not present. However, when budget instability is introduced, the influence upon performance degradation remains, but lifecycle duration is no longer a contributing factor. Thus, adding budget instability into the mix diffuses the effect of lifecycle duration. Since the influence of budget instability appears to be the significant factor upon performance degradation, shorter term projects need protection against unstable fiscal environments. Further work in this area may provide more into this relationship, as well as with other factors not included in this particular model.
**Percentage of Project Budget Increased**

Projects were evaluated for increases to their original budget allocation. For those budgets that were increased, project managers were also asked to provide the percentage increase. The reader may refer to question C4 of the survey in Appendix B. Figure 9.4 highlights the budget increase percentages for the projects by sector.

Over half (55.6%) of the aggregate projects experienced cost overruns. The percentage increases range from 5 to 300% of the original budget. The aggregate project mean was 57.91%. The most frequent value for the military projects was 25%. One military project overran by a whopping 300%. The worst overrun for the civil sector was not much better (240%). The most common overrun percentage for the civil sector was 50%. The commercial projects experienced an equal frequency of increases ranging from 5% to 100%. One can speculate that since the commercial sector does not deal with the funding complexities of the federal budget process, they are in better control of their cost overruns.

![Figure 9.4 Percentages of Project Budget Increases](image)

It is not startling to find a significant correlation between budget increases and schedule slippage in the project data. The budgets had to be increased for 76.5% of the schedules that slipped. Budgets did not have to be increased for 63% of the projects that did not experience a slip. There are certain elements of a project’s cost which are fixed costs. Schedule is one of these fixed cost parameters. If a project’s schedule is slipped, then the fixed costs of the project increase. Longer project completion time amounts to additional costs in a variety of ways, including manpower, materials, contract extensions, etc. Hence, a schedule slip will bring about a cost increase to the project, unless these additional fixed costs are saved in some other aspect of the project.

**Impact of Budget Instabilities**

The extent that any budget instabilities have negatively impacted the project’s schedule and/or performance was studied. The reader may refer to question C2 of the survey in Appendix B. Table 9.8 provides the aggregate project results as well as by project type. Some impact due to budget instability was the most frequent response, comprising 44.4% of the aggregate projects. Taking the position that either a tremendous or significant impact is a cause for concern, then the civil projects experienced this condition 27% of the time, the military projects did 31% of the
time, and the commercial projects 29%. Note that the affect of budget instability upon performance degradation was discussed in a prior section of this chapter.

<table>
<thead>
<tr>
<th>Budget Instability Impact</th>
<th>Project Type</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Civil</td>
<td>Military</td>
<td>Commercial</td>
<td>Aggregated</td>
</tr>
<tr>
<td>Tremendous</td>
<td>15.2%</td>
<td>25.0%</td>
<td>7.1%</td>
<td>15.9%</td>
</tr>
<tr>
<td>Significant</td>
<td>12.1%</td>
<td>6.3%</td>
<td>21.4%</td>
<td>12.7%</td>
</tr>
<tr>
<td>Some</td>
<td>45.5%</td>
<td>31.3%</td>
<td>57.1%</td>
<td>44.4%</td>
</tr>
</tbody>
</table>

Table 9.8 Degree of Project Impact Due to Budget Instability

**Summary of Key Findings**

Budget and Schedule milestone tracking was the predominant metric used for measuring project progress. A variety of metrics were also employed, citing the fulfillment of technical performance requirements and progress reviews as popular measurement alternatives. Closing 75% of a project’s action items on schedule was the most frequent situation, independent of project type. The timely closure of project meeting action items has a significant correlation with schedule delays. As the percentage of on-time closure improves, the likelihood of schedule slippage decreases. There is also a relationship between action items closure and team leader authority. As the level of team leader authority over the project team members increases, the percentage of action items closed on time increases.

Schedule pressure is a significant concern for the project team members, over 80% of the time for all project sectors. Commercial projects may explain this by the demands of market timing. The government projects may explain this due to the loss of critical staff in recent years during an environment of increasing number and complexity of projects. Almost 60% of the projects experienced some form of schedule slip. A six month slip was the most common duration for commercial projects. Military projects commonly slipped between 4 and 9 months. Civil projects most frequently slipped either 8 months or 24 months. Schedule slippage was found to decrease as the level of team leader authority increases. There is also a general trend that the earlier a project’s highest risk technologies begin funding, the higher the likelihood that schedule slippage will decrease.

Almost 50% of the projects experienced some form of performance degradation. Insufficient resources for meeting the desired performance goals was one of the top causes. Supportively, budget instability was found to have a statistically significant influence upon performance degradation, independent of project duration. Relaxation of performance goals was executed by the projects in order to meet the existing budget, staff, and schedule. Technical performance limitations were also cited in equal severity. It was found that for three-fourths of the projects experiencing a schedule slip, some form of performance degradation transpired. By the same token, it was revealed statistically that as lifecycle duration increases, the likelihood of performance degradation rises, provided that budget instability is not present. In contrast, for those projects which experienced performance degradation, there was a 50% likelihood of a schedule delay. We can conclude that schedule slips are not caused solely by performance failures or de-scopes. There was no relationship discovered between performance degradation...
and increase in project scope for this data set. Project scope increased 70\% of the time independent of whether performance was degraded.

Over 55\% of the projects had to increase their budget levels. The most common budget increase for military projects was 25\% of their original baseline budget. The most frequently occurring budget overrun for civil projects was 50\%. Commercial projects overran between the range of 5\% to 100\% in equal likelihood. As you might expect, a significant correlation exists between the need for a budget increase and the likelihood of schedule delay. Budgets had to be increased for over three quarters of the projects which experienced a delay. Since schedule is considered a fixed cost, when the project duration increases, so does the total cost.

At least 39\% of the aggregate projects experienced a significant impact to the schedule and/or the performance due to budget instability. The most common impact level for all three project types was rated as somewhat, accruing 31\%, 46\%, and 57\% of the time for the military, civil, and commercial projects, respectively.
Chapter 10

Conclusions

Thesis Summary

Risk management strategies have become a recent important research topic to many organizations as they prepare to develop the revolutionary complex systems of the future. The merging of multiple disciplines will make it absolutely essential for organizations to practice a rigorous, consistent, comprehensive risk management process, with an unprecedented emphasis on sound systems engineering principles to succeed. It is with this strategy that prior experiences and lessons learned can best be leveraged for continuous improvement. Risk management attitudes must fundamentally change from reactive to proactive as projects increase in complexity and strive for resource efficiencies.

Thinking holistically is an essential trait for those responsible for risk management. The project team should be constantly considering the “big picture” in order to identify and control risks. Effective risk management for developing complex systems requires a systemic view to properly evaluate the interrelationships between known risks. John Elter of Xerox [7] supports this notion by suggesting that for radical technology innovation, the systems people must consider the impacts throughout the entire system. “Risk assessment is all pervasive,” according to one interview respondent, “It enters into everything that you do. Organizations have to focus more on risk awareness.” Although the decisions for accepting risk will vary from project to project, the process should be universal. A universal process across the agency will allow effective mentoring, sharing of lessons learned, and an overall capability that can be developed by the organization. Such a capability is only developed over time with a collective effort toward the same goals. Figure 10.1 illustrates the upward staircase that an organization must travel to establish a capability in risk management. According to the NASA Administrator, NASA has to become more of a learning organization.

Figure 10.1 The Stages of Organizational Learning

Increased mentorship of lesser experienced project managers by veteran project managers must be exercised, especially before the veterans leave the organization. An excess of intellectual capacity is walking out the door without being captured. This loss in organizational knowledge has been a recent difficulty faced by the Air Force, the NRO, and NASA. Loss of critical staff during an environment of increasing number and complexity of missions may explain the significant schedule pressure presently experienced by project team members. Conrow recommends considering the use of risk management mentors to train candidate risk
managers in large organizations where numerous programs exist. This strategy is expected to
greatly increase risk management effectiveness in many government organizations as well as
substantially shorten the time to raise the workforce risk management competency levels. It will
also facilitate the development of strong leadership skills for project managers, which from the
viewpoint of senior managers, has the greatest positive affect on project success.

Senior managers view project managers to be directly responsible for risk management. In
doing so, this does not deliver the proper message to the project team. In this regard, there is a
tendency for senior managers to communicate only through the project manager, and also to
believe that the current reporting status from the project manager represents the actual level of
project risk. This also implies that all of the opportunities for removing risk are localized at the
project level, thus excluding involvement at the organizational level. It is unlikely that at the
level of authority of the project manager, this one individual can be effective at leveraging the
whole organization to reduce risk. Instead, this should be the role of the senior manager.

Changes to the organization's culture are needed to raise workforce awareness and participation
for risk identification, assessment, and prevention. This is a fundamentally difficult challenge
that must be overcome so that many more employees across the agency are engaged in the risk
management process. Ideally, risk management is the responsibility of everyone in the
organization. Also, dissimilar risks are perceived at different levels of an organization (e.g. at
HQ they are political, at the line management level they are organizational, and the project level
they are technical), which can create a barrier to success. The organization needs to develop one
cohesive risk vision to remove this potential impediment.

Senior manager data reveals that the most preferred phases for risk management emphasis
are the planning and design phases. If this is truly the case, then the mentoring of project
managers by senior managers may fail to convey the importance of starting earlier in the project
lifecycle. If at all possible, risk management practices should be emphasized as early as project
initiation, continuing with steady discipline throughout the entire project duration. Reinertsen
[20] emphasizes that the cheapest time of the project’s lifecycle is the preparation phase. Ulrich
and Eppinger [26] also claim that most opportunities for accelerating project schedules arise
during the project planning phase. Accelerating a project before it has begun is much easier than
attempting to expedite the project once it is already underway. Therefore, the highest project
risks should be thoroughly explored during the preparation and planning stages of the project
lifecycle, with robust mitigation strategies investigated. The Futron Corporation study emphasized this specific risk management policy as well.

To many, FBC means product development by dramatic reductions in cost and schedule, at
the expense of performance. However, project managers have recognized revolutionary
technology infusion to be the highest risk driver to FBC projects. Organizations implementing
FBC need to shift from their traditional preoccupation with cost and schedule, to a increased
focus on effectively incorporating new technologies. Although cost and schedule always remain
an issue, experienced project managers feel that incorporating enabling technologies strain the
ability for a project to fully succeed. The use of emerging technologies introduces uncertainty to
make it difficult to control the project’s outcome. The education of FBC to the NASA
community of project and program managers must include sound approaches for effectively
accommodating enabling technologies in the system development process while simultaneously
negotiating the other FBC factors. A related new strategy being exercised by the NRO is the emphasis on performance as a higher project concern than cost containment.

Greenfield [10] claims that long system development times make team continuity difficult. Shorter development times can keep the team together. Large teams have complex communications systems to track and trade risks. Small teams have easier communication and closer technical interaction. The promotion of faster projects by implementing FBC actually helps in this regard. Fully staffing a project team at its onset also helps team continuity by allowing teambuilding activities to achieve maximum team synergy. Adding members downstream in a project makes it much harder for new members to integrate with the existing members. Not only does understaffing hinder team synergy, it has been shown to frequently contribute toward schedule slips and sometimes lead to performance degradation.

The NASA Space Science, Earth Science, and Human Exploration and Development of Space Enterprises each identify well-qualified, cross-disciplinary teams as an essential component for project success. Similarly, senior managers rated project team quality as a top concern, and project managers emphasized the quality and commitment of their team members for success. Staffing a team with the best people also benefits project completion time, since worker quality has been shown to have the largest positive affect on minimizing the schedule. The NIAT Report recommends the involvement of institutional managers and independent experts to increase the speed of detecting and correcting problems. A more effective approach is to enable the project teams with highly talented people, who will make less errors in the first place.

A significant percentage of the technical workforce is viewed to require additional training for future challenges. Since the ultimate success of an organization such as NASA is dependent upon a knowledgeable and skilled workforce, adequate time in employees schedules must be made to facilitate more education. However, the workloads and schedule pressure currently faced by most of the technical workforce create the inability to stay up to date with learning. Therefore, a balance between educational and project-related assignments must be found. If necessary, the total number of projects pursued by an organization at one time should be reduced.

Senior managers consider the interchangeability of engineers among project teams to be more feasible than project managers. Project managers object to this because of their need to maintain a stable team environment. Senior managers also state that staffing changes cannot always be avoided, and at times are even desirable due to the unique skills of employees. However, the value of maintaining a stable team staff throughout a project’s lifecycle was demonstrated by the Mars Climate Orbiter mission. Large organizations such as NASA often operate as a matrix structure for the dynamic deployment of personnel and for encouraging the sharing of information and experiences. But this approach can disrupt team synergy and stability. For this approach to work, a continual educational environment must be established. Enough team members need to develop the necessary multi-disciplinary technical skills to allow for mobility without consequences. The skills of the employee also must be developed to match the needs of multiple projects. The stability of team staff is also influenced by the priority levels set by senior management. Project managers cite senior management commitment to a project as a
strong positive impact because they recognize that the stability of the project resources are tied to this assurance. Since team membership cannot be guaranteed for the project duration even under the best of conditions, the project manager should prepare a risk mitigation plan for handling losses of key technical team personnel. This is essential for minimizing the project impact when a key individual gets unexpectedly pulled from the team to handle a sudden emergency on another mission.

Team confidence has been found to improve as the level of team leader authority increases. It also improves as the team’s understanding of the enabling technologies used by the project increases. Similarly, as the team’s understanding of the project’s objectives and the project’s relationship to the organization’s strategic plan improves, the level of team confidence rises. This suggests that team confidence increases as project management control becomes more localized and the team becomes more in tune with their goals and objectives. Although confidence is a desired characteristic of teams, care must be taken to prevent teams from growing overconfident.

NASA management culture has come to expect that its employees love their job enough to work incredible hours, make personal sacrifices, and continue to do so with minimal forms of reward and/or compensation. Most managers feel the reason NASA employees stay is the personal satisfaction received for contributing to such a uniquely exciting field. In today’s competitive marketplace, this is no longer enough to retain and attract the quality talent that is needed for making revolutionary advances amidst a challenging environment of resources and requirements. More incentives must be provided to attract and retain top notch employees. The NRO has experienced its share of difficulties in cultivating and maintaining a talented workforce, due to the constraints levied on rewards and promotions for its people. Similarly, the Air Force is working at adopting a policy for recruiting, retaining, and rewarding the best technical people to ensure its superiority for the future.

As discovered by the primary concerns of senior managers, the emphasis upon open, clear communications is vital for the organization to be successful at project management. Lipnack and Stamps [14] state that an individual without information cannot take responsibility, and an individual who is given information cannot help but take responsibility. Therefore, project managers can help the fate of their projects by effectively keeping their top managers in the loop concerning all risk aspects of a project. Every type of communication tool should be utilized for communicating both horizontally and vertically within the organization. Communication tools become ever so more important when communicating across organizational boundaries.

Senior managers must exercise their power to effectively deter external influences from projects. The project manager must be freed up from such interferences, so that time is more wisely spent on the technical coordination and evaluation of complex system development. The more support a project team is provided to negotiate its external influences, the greater the probability of project success. More time focused on system development translates into a higher likelihood that it will be developed right the first time. Figure 10.2 illustrates some of the many external influences that exist on a NASA project. It becomes quickly obvious that a project can suffer demonstrably when one or more of these influences create project instability. One of the primary issues which faced the NRO was the increasing demand for meeting
customer expectations. This alteration in priority brought about a decline in the technological competitiveness of their satellites. Rechtin states complex systems cannot be optimum to all parties concerned. The project manager must be a successful articulator of this fact to all of the external influences. The earlier other parties accept the reality that the project manager cannot meet everyone’s expectations, the sooner he/she can concentrate on the technical work at hand.

Figure 10.2 Typical External Influences on a NASA Project

The NASA Space Science and Earth Science Enterprises would benefit from leveraging some of the risk management strategies and lessons learned from the Human Exploration and Development of Space Enterprise. There does not appear to be enough cross-fertilization of this information presently ongoing. In such a large organization, it is not unusual for the left hand not to be keeping up with what the right hand is doing. These human space flight strategies and lessons have evolved over the years, as the agency has continually pursued increases to the level of safety. This great wealth of experience internal to the agency is worth tapping into by the developers of robotic spacecraft. This also makes good sense from the standpoint of learning efficiency.

Both senior managers and project managers have expressed significant concerns for adequate project resources. A project must begin with sufficient personnel and fiscal resources to stay on course and to meet the creative demands of the challenge. Figure 10.3 illustrates the tradeoff an organization makes when focusing on creative innovation as opposed to operational efficiencies [25]. Applicable to NASA, the graph suggests that as efficiency increases, creativity will suffer. Point 1 represents a time in past history when the creativity of NASA was extremely high, at the expense of project efficiency. Using the example of landing men on the moon, the creativity ranks amongst the highest in all of history, but project efficiency was low. A great number of employees were involved with an almost unlimited budget available. Point 2 represents a typical project today, constrained by both organizational efficiencies and the push for FBC. These limitations compromise an organization’s ability to creatively innovate. Key ingredients to
DARPA’s success for developing revolutionary complex systems are the creativity of their program managers, and the working environment that exists to exploit this behavior.

Future NASA missions would benefit by reframing the views which the public has traditionally taken regarding acceptable risk. The public should always view mission outcomes as eventual gains, not losses. In order to do this, NASA may need to emphasize the likelihood of failure more often to the public, instead of projecting too high a level of confidence. Framing the effort to the public in this way may help to reinforce the aspect that what is learned through failure is an important gain in terms of progress for space exploration.

![Creativity vs. Efficiency Curve](image)

**Figure 10.3 Creativity vs. Efficiency Curve**

This research has contributed to the programmatic risk management of complex space systems development in the following three ways. First, risk management perspectives of senior managers and project managers have been collected and evaluated. These managers come from a variety of aerospace and aeronautical organizations, and are responsible for the development of complex systems which push the state-of-the-art in science and technology. In doing this, some of the primary risk drivers and decision-making mechanisms that contribute to the success or failure of projects have been revealed. Since the subject of risk management is not universally understood, and differs in both strategy and implementation approaches from organization to organization, an identification of some of the various approaches has been described. Second, a number of complex system projects with one or more enabling technologies were evaluated to determine project manager approaches to the management of programmatic risks. The project conditions under which they worked were studied to identify any notable conditions which have a significant effect on the performance, cost, and schedule of a project. Third, discontinuities between the perspectives of senior managers and project managers were discussed. These findings shed light on the steps that organizations should take to unify their risk management efforts in support of increased project success.

The key findings and recommendations described in this chapter are useful to NASA as the agency transforms its NIAT Report actions into implementation activities. Some final thoughts that have been cited in earlier chapters are now included here.

1. High risk, enabling technologies must be funded early in a project’s lifecycle. This is necessary to manage the uncertainty associated with technology development, until a successful technology development pipeline is fully operational.
2. As the number of enabling technologies increase for a project, so does the influence exerted by other projects in the organization over these technologies. This creates a added degree of requirements complexity for the project. Thus, management must exercise caution when considering to accommodate the needs of other projects with the same technology development.

3. Projects should focus on attacking the toughest risks first and keeping them highly visible to all levels of management. These risks are those which fall on the critical path. The push toward reduced development schedules leaves less time to address a problem. Thus, the earlier a problem is discovered, the lower the cost of fixing it.

4. The level of operations personnel, key customers and stakeholders, the R&QA group, senior management, scientists, the entire project team, and peer review boards were found by the research data to be lower than that desired by the NIAT Report for early project involvement in risk management activities. Mandatory training for technical project employees would help to raise the awareness as well as instruct how to approach identifying and classifying risks. Conrow states that in order for risk management to be effective, the team members must consider it as part of their daily decision-making process. Suitable incentives should be provided for those who identify potential project risks, to encourage this behavior. More project team involvement with the R&QA group should be promoted, so that the organization takes full advantage of their available risk management resources.

5. The importance of budget stability cannot be overemphasized. Budget instability was found to be a significant factor for increasing the likelihood of performance degradation. Once performance is impacted, schedule delays are to be expected in order to sustain the original performance goals of the project.

This summary wraps up with a citation. On October 16, 2000, the NASA Administrator Daniel Goldin proclaimed to a room full of MIT graduate students the following message:

“If you are not afraid to fail, are free to dream, and you execute, you will get there.”

This statement is relevant to the research findings presented in the following way. In order to rid the fear of failure, senior management must encourage their project managers to accept challenging risks without the apprehension of mission failure resulting in damaging their career. Public perception must be improved by educating to the public the value in taking bold risks and failing. It is only through occasional failure that learning really occurs, and improper methodologies revealed. NASA is one of the most conducive work environments for transforming one’s vision for improving the future into reality. Creativity and innovation must not be hampered by such organizational crutches as overburdened employee schedules, lack of knowledge transfer, and changing strategic priorities. Proper execution entails senior management providing their project managers the necessary stable support, mentoring, oversight, and freedom from external influences to facilitate success. These activities collectively will lead to the success of going where no man has gone before.
Future Work

Much more work can be done with the data collected during this research. There are many interesting correlations between the survey questions that can be statistically analyzed to develop further, more in-depth insights. More multivariate correlations and regression analysis may yield additional unique combinations of variables that create a particular impact to the performance, cost, and schedule of a project.

More survey data can also be collected. The next step should be to dramatically reduce the surveys in terms of broadness, instead focusing in depth on a particular area of interest covered by this research, e.g. only performance, cost, or schedule. The researcher would also benefit by first collecting a suitable list of questions that others would ask if they were conducting such a survey. This captures valuable questions that the researcher may overlook. If one has enough time at their disposal, obtaining several hundred responses from projects would be desirable. One consideration of the survey administrator might be to require only failed missions as responses. Another consideration would be to acquire a relatively equal set of failures along with solid success stories, and focus the research on the similarities and differences between the two. Yet another follow-on research approach would be to target specific organizations in the project sectors, obtaining a critical mass of respondents from each, to investigate the different approaches among key organizations developing revolutionary complex systems.
References


References (cont'd)


Appendix A

Risk Drivers Survey For Senior Administrative Managers

This survey is being conducted as part of a Master’s thesis on Risk Management Strategies for Developing Complex Systems, at Massachusetts Institute of Technology (MIT). The questions that follow focus mainly on the preparation and planning phases of a project. Your candid responses are appreciated.

Instructions:
Use the Tab and Shift+Tab keys to move between fields. You may also use the mouse and click on the shaded area to select it. When you have completed the survey, please save the file by selecting Save As on the File menu. Please name the file using the convention of Lastname–Company [e.g. Panetta-GSFC.doc]. Please return the saved file as an email attachment to ppanetta@mit.edu.

Preliminary

P1. What is the name of your organization?

P2. What is the official title of your position?

P3. How long have you served in this position?

   1 yr or less

Risk Driver Questions

R1. Which statements best describe the type of project manager (PM) you feel would be acceptable to lead a complex system development that is dependent upon a significant number of emerging technologies? [check all that apply]

- PM is among the best and brightest employees in the organization. PM learns everything quickly, but is still somewhat inexperienced at managing this type of endeavor.

- PM has substantial technical product development experience but has little or no real management experience.

- PM demonstrates sound personnel management skills but is not that strong technically. PM relies mainly on others to make tough technical decisions.

- Only a veteran PM who has numerous successes under his/her belt is appropriate for this position.
R2. Who do you feel the responsibility for a project’s risk management should *primarily* rest with? [check only one]

- The project manager
- The Reliability & Quality Assurance Group providing oversight to the project
- The project team members doing the technical work
- The stakeholders during project reviews
- Equally among everyone involved with the project in some way
- Other (enter here):

R3. During what phase(s) in the project should *obvious* steps in risk management *primarily* be emphasized? [check all that apply]

- Preparation phase
- Planning phase
- Conceptual Design phase
- Development phase
- Operations phase

R4. How would you define “appropriate” risk for a complex systems project in your organization?

R5. What percentage of the technical workforce presently possesses a sufficient level of training for the challenges that lie ahead in developing revolutionary complex systems?

- 80 to 100%
- 60 to 79%
- 40 to 59%
- 20 to 39%
- 0 to 19%

R6. How do you view a project manager that suddenly communicates a potential risk that was otherwise unaccounted for earlier in the project lifecycle? [check only one]

- PM is weak at risk management and is likely to fail with this project
- PM is demonstrating inexperience with risk management, but has good common sense
- PM is doing the right thing by bringing it to *our* attention
- PM is being proactive and is demonstrating effective risk management
- Other (enter here):
R7. How valuable would you find it to have the ability to prioritize the organization’s projects according to schedule, performance (quality), cost, scope, and innovation?

☐ Extremely valuable
☐ Very valuable
☐ Sometimes valuable
☐ Rarely valuable
☐ Not valuable at all

R8. How much of an impact do you feel that staffing changes *in between* phases of the project lifecycle affect the outcome of a given project?

☐ Tremendous impact
☐ Considerable impact
☐ Some impact
☐ Little impact
☐ No impact at all

R9. In terms of project success, what are the top 3 things you worry about the most?

(1)

(2)

(3)

R10. By what specific method(s) are risks identified in your organization?

R11. What things (if any) do you feel your organization must do differently in order to successfully manage the risks associated with developing future products or systems that integrate the Biological/Information Technology/Physical domains?
R12. How strongly do you agree with the belief that engineers are “interchangeable” on project development teams (e.g. no real impact to exchange one mechanical engineer for another)?

- [ ] Fully agree
- [ ] Somewhat Agree
- [ ] Neither agree nor disagree
- [ ] Somewhat disagree
- [ ] Fully disagree

R13. How well do you believe the project development teams in your organization understand how their project specifically relates to and/or ties into the organization’s long-term strategic plan?

- [ ] Great understanding
- [ ] Good understanding
- [ ] Adequate understanding
- [ ] Poor understanding
- [ ] No understanding

R14. What do you think has the strongest *positive* impact on a project?


R15. What do you think has the strongest *negative* impact on a project?


R16. What questions come to mind that you would have asked if you were conducting this survey?


Thank you for taking the time to complete this survey. Your responses are deeply appreciated. In return for your participation, I will provide you a copy of the completed thesis, upon request.

Peter Panetta
NASA – Goddard Space Flight Center
MIT System Design & Management Fellow

107
Appendix B

Risk Drivers Survey For Project Managers

This survey is being conducted as part of a Master’s thesis on Risk Management Strategies for Developing Complex Systems, for the System Design and Management Program at Massachusetts Institute of Technology (MIT). The questions that follow focus mainly on the preparation and planning phases of a project.

Some of the survey questions are general in nature and are included to frame your project manager experience, or to probe your attitude or feelings toward a specific topic. These questions are denoted with an asterisk (*). All other survey questions are designed to target one specific complex systems project from your present or past management experience. After selecting a challenging complex system project from your experience, please base all of your answers to these questions on this particular project only. Your candid responses to all questions are appreciated. Unless otherwise specified, please select only one answer for the multiple choice questions.

Your responses to this survey will remain confidential. The response data will be aggregated and statistically evaluated to assist in the identification and planning for specific risk management strategies.

Your participation in this survey is deeply appreciated.

Instructions:
Use the Tab and Shift+Tab keys to move between fields. You may also use the mouse and click on the shaded area to select it. When you have completed the survey, please save the file by selecting Save As on the File menu. Please name the file using the convention of Lasiname-Company [e.g. Panetta-GSFC.doc]. Please return the saved file as an email attachment to ppanetta@mit.edu.

Preliminary Data
P1. * As a project manager, how many total projects have you been responsible for?
   1

P2. For the project on which you will base the survey answers, what is the project’s initial lifecycle duration?
   
   ☐ Less than 1 year
   ☐ Between 1 and 2 years
   ☐ Between 2 and 3 years
   ☐ Between 3 and 5 years
   ☐ Over 5 years

P3. What type of project is this? [check only one]
   
   ☐ Civilian US Government
   ☐ Military US Government
   ☐ Commercial
P4. For the project on which you will base the survey answers, what is the project’s initial budget?

- Less than $500K
- Greater than $500K but less than $2M
- Greater than $2M but less than $10M
- Greater than $10M but less than $25M
- Greater than $25M but less than $100M
- Greater than $100M but less than $200M
- Greater than $200M but less than $500M
- Greater than $500M but less than $1B
- Greater than $1B

P5. For the project on which you will base the survey answers, what is the total number of technical members on the development team (independent of their physical location and independent of the amount of time each contributes to the project)?

- 10 or less
- 11 to 25
- 26 to 50
- 51 to 100
- 100+

P6. For the total number of technical members specified in question 4, what is the total full-time equivalent (FTE) of the development team? [FTE is the total amount of person-years; e.g. 2 people full time plus 4 people half time for one year = 4 FTE]

Enter number:

P7. For the project on which you will base the survey answers, which best describes the distribution of company employees to support contractors?

- ~100% company employees
- ~75% company employees, ~25% support contractors
- ~50% company employees, ~50% support contractors
- ~25% company employees, ~75% support contractors
- ~100% support contractors

P8. For the project on which you will base the survey answers, how many enabling new technologies are originally planned for infusion into this project?

- None
- 1
- 2 to 5
- 6 to 10
- More than 10
Performance Risks

R1. Regarding prior lessons learned from relevant projects, what level of review and understanding do you feel that your project team members possessed before they began working on the project?

- Thorough review and understanding
- Good review and understanding
- Average review and understanding
- Poor review and understanding
- No review and understanding

R2. How many system architecture peer reviews were implemented prior to the project committing to a single point design?

Enter number: 

R3. Was the project’s scope ever increased independent of your personal control (e.g. dictated to you from higher up due to external influences)?

- Yes
- No

R4. To what extent were the results of prior projects used to determine the project’s scope, schedule, budget, and performance?

- Predominately used
- Significantly used
- Somewhat used
- Barely used
- Not used at all

R5. Which best describes the method most often used to make technical tradeoff decisions? [check only one]

- By total team consensus
- By team majority vote
- By project manager decision
- By inputs from the Project Manager, Lead Systems Engineer, and several other Lead Personnel
- By peer review
- By stakeholder review
- Imposed from higher authority
R6. How do you rate the level of confidence that your team members showed toward meeting the cost, schedule, and performance goals of the project?

- [ ] Extremely confident
- [ ] Very confident
- [ ] Somewhat confident
- [ ] Barely confident
- [ ] No confidence at all

R7. * Rank the following statements in the order that best reflects your attitude toward a successful product development approach [1 = most successful, 4 = least successful]:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Take the time to design and build it right the first time; catching problems in test phase should not be the baseline</td>
</tr>
<tr>
<td>2</td>
<td>Build a little and test a little, discovering and fixing problems as you go</td>
</tr>
<tr>
<td>3</td>
<td>Design and build quickly, then test exhaustively to make sure all of the bugs are eliminated before delivery</td>
</tr>
<tr>
<td>4</td>
<td>Design, build, and test quickly; plan for making fixes/upgrades in the field after receiving user feedback</td>
</tr>
</tbody>
</table>

R8. Who have actively participated in the identification and classification of project risks? [check all that apply]

- [ ] The project manager
- [ ] The lead systems engineer
- [ ] The lead subsystem engineers
- [ ] Some of the project discipline engineers
- [ ] All project team members
- [ ] Reliability & Quality Assurance (R&QA) personnel supporting the project
- [ ] Stakeholders
- [ ] Senior management
- [ ] Scientists
- [ ] Peer review board
- [ ] Other (enter here):

R9. Did the project experience any degradation in performance from its original requirements?

- [ ] Yes
- [ ] No

If Yes, please elaborate:


R10. What metrics, if any, were used to measure how well the project was doing at any point in time?

Cost Risks

C1. Of the total budget *requested*, what percentage of financial resources did you *initiate* your project with?

- □ 80 to 100%
- □ 60 to 79%
- □ 40 to 59%
- □ 20 to 39%
- □ 0 to 19%

C2. To what extent have any budget instabilities negatively impacted the project’s schedule and/or performance?

- □ Tremendously
- □ Significantly
- □ Somewhat
- □ Barely
- □ Not at all

C3. * If a project were to receive an insufficient portion of its funding *during the first 25*% of its lifecycle, which best describes your view of the impact to the project’s eventual success?

- □ Catastrophic
- □ Significant
- □ Manageable
- □ Little
- □ No impact at all

C4. Did the project’s budget have to be increased from its original allocation?

- □ Yes
- □ No

If Yes, by how many %?
Schedule Risks

S1. Of the total personnel resources requested, what percentage did you actually begin your project with?

- [ ] 80 to 100%
- [ ] 60 to 79%
- [ ] 40 to 59%
- [ ] 20 to 39%
- [ ] 0 to 19%

S2. Which best describes the visibility of the latest master project schedule to all of the team members? [check only one]

- [ ] Handed out at team meetings
- [ ] Posted on a common wall
- [ ] Stored electronically on a project website
- [ ] Shown to team members upon their request
- [ ] Not distributed at all

S3. * Of the following 3 choices, which do you believe has the largest impact on shortening a project’s completion time frame?

- [ ] An increase in worker productivity
- [ ] An increase in worker quality (i.e. accuracy/error-free work)
- [ ] A reduction in the time to discover additional tasks required (due to work errors and/or incomplete requirements)

S4. How much of a schedule buffer is carried for contingency?
Enter number of %:

S5. To what extent do you feel that your project team members are under pressure to meet critical deadlines to keep the project on schedule, or to make up time for being behind schedule?

- [ ] Always
- [ ] Frequently
- [ ] Sometimes
- [ ] Rarely
- [ ] Never
S6. Which statement best describes the typical number of other projects a team member concurrently works on in addition to your project?

- [ ] No other projects
- [ ] 1 other project
- [ ] 2 other projects
- [ ] 3 other projects
- [ ] 4 or more other projects

S7. Did this project experience a schedule slip?

- [ ] Yes
- [ ] No

If Yes, by how long?:

Technology Risks

T1. Which best describes the project's risk mitigation strategy that was implemented for an enabling new technology development? [check only one]

- [ ] Request a budget increase to protect against delays in delivery or problems in meeting required performance levels
- [ ] Develop one or more backup technologies in parallel of critical new technologies for ready substitution if necessary
- [ ] Adapt the most compatible commercial-off-the-shelf product available as the resolution
- [ ] Delay project schedule until technology is successfully delivered
- [ ] Other (enter here):

T2. Which best describes how well the project team members truly understood the technologies selected for use?

- [ ] Extremely well
- [ ] Very well
- [ ] Average
- [ ] Poorly
- [ ] Not at all

T3. At which stage did the project's highest risk technologies begin funded development? [check only one]

- [ ] Before project's initial conception
- [ ] Project Preparation phase (a.k.a. Proposal phase)
- [ ] Project Planning phase (a.k.a. Formulation phase)
- [ ] Project Design phase (a.k.a. Early Implementation phase)
- [ ] Project Development phase (a.k.a. Considerably into Implementation phase)
T4. To what extent were the selection of enabling new technologies influenced by their perceived additional benefit to future projects or other presently ongoing projects?

- Predominately
- Significantly
- Somewhat
- Barely
- Not at all

T5. How many peer reviews for the project’s enabling new technologies were implemented in the early conceptual design stages (prior to design / start of implementation phase)?

Enter number:

T6. * How many peer reviews for the project’s enabling new technologies do you now feel are necessary in the early conceptual design stages (prior to design / start of implementation phase)?

Enter number:

Organizational / Business Process Risks

B1. How well do you rate your project team members understanding of how the project specifically relates to your organization’s strategic plan?

- Thorough understanding
- Good understanding
- Adequate understanding
- Poor understanding
- No understanding

B2. To what extent would you rate the team members’ understanding of the project’s mission statement, primary objectives (live or die goals), and secondary (desirable but not essential) objectives during the design & development phases?

- Thorough understanding
- Good understanding
- Adequate understanding
- Poor understanding
- No understanding
B3. Of the following choices, which is the best estimate of how often your project team meets as a whole (including offsite team members physically present or tied in via video/teleconferencing)?

- [ ] Once per week
- [ ] Once every 2 weeks
- [ ] Once every 3 weeks
- [ ] Once per month
- [ ] Once every 2 months
- [ ] Other (enter here):

B4. * Assuming working under the NASA “Faster, Better, Cheaper” paradigm, rank the following requirements/constraints in order of how much you feel they increase the risk of project failure [1 = risk increased the most, 5 = risk increased the least]:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Optimum Performance</td>
</tr>
<tr>
<td>2</td>
<td>Minimum Schedule Time Frame</td>
</tr>
<tr>
<td>3</td>
<td>Minimum Cost</td>
</tr>
<tr>
<td>4</td>
<td>Revolutionary Technology Infusion</td>
</tr>
<tr>
<td>5</td>
<td>Mission Complexity</td>
</tr>
</tbody>
</table>

B5. How involved were the key customers / stakeholders in developing the project’s specifications?

- [ ] Substantially (i.e. involved in all possible respects)
- [ ] Above average (i.e. involved to a large extent)
- [ ] Somewhat (i.e. involved in some respects)
- [ ] Very little (i.e. involved in a few issues)
- [ ] Not at all

B6. How involved were operations personnel in developing the project’s specifications?

- [ ] Substantially (i.e. involved in all possible respects)
- [ ] Above average (i.e. involved to a large extent)
- [ ] Somewhat (i.e. involved in some respects)
- [ ] Very little (i.e. involved in a few issues)
- [ ] Not at all

B7. How involved were scientists in developing the project’s specifications?

- [ ] Substantially (i.e. involved in all possible respects)
- [ ] Above average (i.e. involved to a large extent)
- [ ] Somewhat (i.e. involved in some respects)
- [ ] Very little (i.e. involved in a few issues)
- [ ] Not at all
B8. Which best describes how project meeting action items were addressed, including how expeditiously they were closed?

- Very seriously: ~100% are aggressively pursued to closure on schedule
- Pretty seriously: ~75% are closed on schedule, ~25% remain open past their due dates
- Somewhat seriously: ~50% are closed on schedule, ~50% remain open past their due dates
- Barely seriously: ~25% are closed on schedule, ~75% remain open past their due dates
- Not seriously at all: ~100% remain open past their due dates

B9. * From your project management experience, how strongly do you agree with the belief that engineers are "interchangeable" on your team (e.g. no impact to exchange one mechanical engineer for another)?

- Fully agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Fully disagree

B10. Which statement best describes how much authority you have as a leader over the engineering team members?

- Lightweight Team Leader: a functional manager (FM) has both administrative and technical authority
- Balanced Matrix: you have equal authority along with an engineer’s functional manager for both administrative and technical details
- Heavyweight Team Leader: You have full technical authority while the FM handles all administrative details
- Full Authority: you have both administrative and technical authority over the team members
- Other (enter here):

B11. Which statement best describes the amount of co-location for this project? [check only one]

- Team members physically reside in their functional organization
- Some of the team members are co-located to my organization
- Most of the team members are co-located to my organization
- The entire team is co-located to my organization
- Other (enter here):

B12. Rank the following items in order of how much they challenged the product development process [1 = most challenging, 3 = least challenging]:

- Responding to external events and/or influences
- Making system structural changes / tradeoffs
- Absorbing changes in project dynamics (growth, stability, staffing)
General

G1. What do you think had the strongest *positive* impact on your project?

G2. What do you think had the strongest *negative* impact on your project?

G3. What questions come to mind that you would have asked if you were conducting this survey?

G4. Please use this space for any additional comments to support any of the previous survey questions. Please provide the question number you are referring to.

Thank you very much for taking the time to complete this survey. In return for your participation, I will provide you a copy of the completed thesis, upon request.

Peter Panetta
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